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Yucca Mountain: Should We Delay?

RODNEY C. EWING AND ALLISON MACFARLANE ("Yucca Mountain," Policy Forum, 26 April, p. 659) suggest that the decision to site a high-level nuclear waste repository at Yucca Mountain, Nevada, should be delayed until all relevant scientific issues are addressed. Insisting on comprehensive knowledge is neither possible nor necessary to assess the suitability of Yucca Mountain. This standard for proceeding can never be met by any proposed repository site. Furthermore, insisting on scientific understanding of all possible processes only diverts limited resources from the few key processes that control the long-term performance and safety of a geological repository.

Ewing and Macfarlane are concerned that "[t]he determination of compliance depends almost exclusively on the results of the total system performance assessment." Yet the National Academy of Sciences (NAS) has stated that (*1*, p. 8) "[t]he only way to evaluate the risks ... and to compare them with the standard is to assess the estimated potential future behavior of the entire repository system and its potential effects on humans. This procedure ... is called performance assessment ... The results of compliance analysis should not, however, be interpreted as accurate predictions of the expected behavior of a geologic repository. No analysis of compliance will ever constitute an absolute proof; the objective instead is a reasonable level of confidence in analyses that indicates whether limits established by the standard will be exceeded. Both the USEPA [Environmental Protection Agency] and USNRC [Nuclear Regulatory Commission] have explicitly recognized this objective."

An issue raised by Ewing and Macfarlane is the primary reliance placed on engineered barriers over geological barriers. This well-accepted strategy applied to multiple-barrier repositories is followed in Sweden (*2*), Finland (*3*), Switzerland (*4*), and Japan (*5*). The Swedish repository program (*6*, p. xvii) notes that "[t]he primary function of the rock is to provide stable mechanical and chemical conditions over a long period of time so that the long-term performance of the engineered barriers is not jeopardized." Initial emphasis on the performance of engineered barriers in safety assessments does not imply the lack of performance by geological barriers, but recognizes that the contribution from engineered barriers can be more rigorously evaluated than that of geological barriers (*7*).

Ewing and Macfarlane cite several technical areas they believe need more study. Not all processes, however, significantly impact repository safety. Any list of possibly important processes must be screened to identify those processes that significantly impact repository safety (*8*).

It has been noted (*9* pp. 771–772) that "[f]or the mission of the repository program, sufficiency of understanding is met when a suitably reliable assessment of successful performance has been made. Complete understanding and characterization are not necessary, nor can they ever be achieved. Reliable performance assessment will never be based on an encyclopedic and encompassing analysis of all phenomena that could, in principle, affect repository performance, nor should it be. Trying to develop global models that include all phenomena introduces unnecessary uncertainties and it dilutes our effort towards studying the important processes."

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Are there sufficient scientific understanding and performance assessment analyses today to support a decision to recommend the Yucca Mountain site and proceed to the next step in assessing the overall safety of a repository located at this site? Given the available data and the extensive set of performance assessment analyses conducted by the Department of Energy (DOE), the NRC (*10*), and other organizations (*11*), the answer is definitely "yes."

Contrary to the impression given by Ewing and Macfarlane, a site recommendation now does not end the DOE's obligation to continue work to demonstrate the safety of a Yucca Mountain repository. This obligation persists during the fully reversible licensing process established by NRC regulation, with additional, independent technical oversight provided by the Nuclear Waste Technical Review Board, as well as the NAS as appropriate. Our support of the site recommendation in part reflects our confidence that under this licensing process, the DOE will continue to conduct the scientific studies necessary to further confirm repository safety, including the regulatory-mandated performance confirmation testing program planned over the next 50 to 100 years, until the time final closure might be approved. During this performance confirmation period, technical issues can be further investigated and designs optimized, recognizing that at each step a decision to proceed will be based on reassessment of the long-term safety of the repository.

dEbates!

Discussion of the Policy Forum "Yucca Mountain" continues online in *Science*'s dEbates

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EWING AND MCFARLANE RAISE CONCERNS about the Yucca Mountain waste repository site that require thoughtful consideration, especially the changing understanding of the geology of the site and an increasing dependence on the use of containers for the nuclear waste. However, the influence of such uncertainties on the safety of the repository will surely be addressed in the rigorous licensing process to be conducted by the NRC—assuming that Congress supports the President's decision to proceed in this orderly manner.

The 40 years of study already invested in the disposal of nuclear waste, with some two decades focused on Yucca Mountain in particular, should not be cast aside with the implication that our government is acting in haste. If subsequent investigations during the licensing process reveal any substantive reason for preventing the long-term storage of nuclear waste, we should remember that the repository is being designed to allow full retrieval of all waste for at least 100 years. Certainly, that should allow sufficient time to build the confidence required before any decision is made on permanent storage.

There is indeed some risk associated with the Yucca Mountain site, as Ewing and Mcfarlane point out. But there is far greater risk in not proceeding with the licensing process. The latter path would, at a minimum, leave an increasing accumulation of spent fuel at the many reactors in the United States for many decades to come. It would also prevent humanity from access to perhaps the only source of energy that can legitimately wean the United States away from its dependence on Middle Eastern oil. This is a price we dare not pay.

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EWING AND MACFARLANE ARGUE THAT THE Yucca Mountain program for disposing of high-level nuclear waste should not go forward "until the relevant scientific issues have been thoughtfully addressed." They quote Thomas Jefferson: "Delay is preferable to error." To examine whether this is a reasonable decision rule in this case, we need to compare the costs and risks of delay with those of moving ahead with the program.

Delay is expensive. In the past 20 years, the estimated cost of Yucca Mountain has escalated from about $10 billion to almost $60 billion. The program is 12 years behind schedule, and this delay has contributed substantially to the cost escalation. Further delays will cost about $600 million per year.

Delay is risky. Leaving nuclear waste spread out at 75 sites across the United States involves a higher risk of theft and misuse of nuclear materials when compared with geological disposal, leaves multiple targets for terrorism, and may, even under the best of circumstances, have human health consequences.

> **"Delay is expensive ... the estimated cost of Yucca Mountain has escalated from about $10 billion to almost $60 billion."**

With careful scientific studies, long-term monitoring programs, and flexible strategies for implementing the Yucca Mountain program, we can minimize the risks and contain the costs of disposing nuclear waste. Further delays of the Yucca Mountain program are likely to be more risky and more costly than moving ahead now.

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Response

WE MAINTAIN THAT DESPITE THE SIGNIFICANT efforts of DOE scientists, "sound science" (*1*) does not support the DOE recommendation of Yucca Mountain as a geologic repository for high-level nuclear waste. Unresolved technical and scientific issues remain, and the present decision is premature. We are not alone in our assessment of the status of the scientific basis for this decision (*2–5*). However, we are not calling for complete knowledge and understanding of the site before the emplacement of waste. We accept that any analysis of this type will inevitably contain large uncertainties. This is why the balanced use of multiple barriers, engineered and geologic, has long been essential to the strategy of geologic disposal (*6*). On the contrary, recent analysis shows that most of the projections of the performance of the repository rest on extrapolated, and optimistic, assessments of the long-term behavior of the metal waste container. Given the complexity of the Yucca Mountain site and the unusual strategy that is being pursued by the U.S. program (i.e., disposal in the unsaturated zone above the water table under oxidizing conditions), the scientific demonstration of safety remains an unanswered challenge, particularly because complex, highly coupled systems do not usually fail from a single cause, but from unanticipated conditions or sequences of events that usually are not evident in the analysis (*7*).

The tragedy of the present situation is that there are no alternative sites or strategies. The Nuclear Waste Policy Act Amendment of 1987 narrowed the U.S. program to a single site. Congress is now being asked to make a major public policy decision without a full range of alternatives and their associated risks described. A recent report of the National Research Council has recommended that each national program "prepare an objective, comprehensive comparison of realistic alternatives, including a description of the current safety and security afforded by the status quo storage configuration over long time periods ..." (*8*, p. 43). We know of no substantive and thoughtful analysis of the risks and impact of continued surface storage over a period of 10 to 100 years, although many analyses allude to these risks. A delay of a decade could also provide time to resolve critical technical issues related to the future development of the nuclear fuel cycle. In the United States, we presently consider a range of possibilities from transmutation of waste to reprocessing of spent fuel. These decisions will impact the need, timing, and design of a repository.

Some have suggested that we simply leave the technical review of the site to the NRC. However, the NRC is legally constrained by its own rule-making and will not review alternatives. The National Research Council recommended that "regulatory decisions should in general be based on more than a single numerical figure of limit ..." (*8*, p. 47). The present NRC rule, in effect, determines compliance on the basis of a calculated dose some 20 km from the repository for 10,000 years. The use of this single performance metric obscures the role of multiple barriers.

Why delay now? There are outstanding technical and scientific issues that can and should be resolved. Apted *et al.* argue that even a several-orders-of-magnitude improvement in waste form (i.e., spent nuclear fuel) durability is not an important factor in performance of a repository, but the analysis they cite was not of Yucca Mountain and was published in 1983 (*9*). There has been a substantial increase in our knowledge of Yucca Mountain and our understanding of the behavior of waste form materials in a variety of geologic environments during the past 19 years. Why not use this knowledge? If we begin construction of the repository now, the financial and political investment in this site will, as it does now, drive future decisions. The well-known "sunk cost" effect echoes through the responses from our colleagues. The prospect of retrieving the waste offers little solace. There are no criteria for retrieval and no site for the retrieved waste.

What of the future? Congress will almost certainly overrule Nevada's objections, and the project will go forward. Despite this decision, surface storage of spent fuel will continue for decades. We still need to analyze the risks and take the required actions to immediately secure these surface storage facilities. The next major decision will require Congress to increase the capacity of the repository, because by 2010 the amount of spent nuclear fuel will nearly equal the legislated capacity of 70,000 metric tons. The increased capacity will further impact the design and safety analysis of the Yucca Mountain repository. Although Yucca Mountain may finally be the first geologic repository for high-level nuclear waste, it may, in the absence of a fair process and substantive analysis, be the last repository in the United States. This is a poor foundation on which to base the future of nuclear power.

"If we begin construction of the repository now, the financial and political investment in this site will ... drive future decisions."

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HIV-1 Diversity and Vaccine Development

THE INEXORABLE SPREAD OF THE HUMAN immunodeficiency virus (HIV) has prompted an urgent effort to develop an AIDS vaccine. The diversity of HIV in human populations poses an unprecedented challenge for the development of a highly effective vaccine. A recent meeting at the Vaccine Research Center at the National Institute of Allergy and Infectious Diseases, National Institutes of Health, organized in collaboration with the World Health Organization and the Joint United Nations Programme on HIV/AIDS, focused on the genetic diversity of HIV and strategies to develop vaccine candidates. More than 95% of new HIV infections occur in developing countries, and effective vaccines would no doubt help to control the epidemic. A high level of diversity of HIV exists among different populations, and vaccine trials for the developing world will also need to address factors such as concurrent infectious diseases, access to health care, and the ability to deliver and test vaccines. The relevance of HIV genetic diversity to vaccine efficacy remains unknown.

The meeting led to consensus recommendations on how best to address this scientific issue in the context of current vaccine efforts. Parallel trials of vaccine candidates from different clades are needed to address their relevance to immune protection. Although clade B is the most frequent virus type in the Americas and in parts of Asia, clade C viral strains are most prevalent in southern Africa and Asia and represent the most abundant genetic subtype worldwide. In Africa, clades A, C, and D cause the vast majority of HIV-1 infections. Recent analyses of genetic relatedness indicate that the diversity within any one clade of HIV may be no greater than the diversity between clades (*1*, *2*), although for specific gene products, such as Env, the intraclade diversity may be less than the variation between two clades. In addition, the degree of diversity varies according to viral gene product. Therefore, it is important when matching genetic sequences to consider the specific viral gene product used as an immunogen.

Although genetic diversity may affect immune responses to HIV-1, its significance for protective immunity is unknown. Significant cytolytic T lymphocyte cross-reactivity can be demonstrated between Gag proteins of clades B and C, but clade-specific epitopes are also evident. Similarly, antisera from one clade can neutralize another, and neutralization phenotype does not correlate with the clade of origin (*3*). Thus, the importance of matching clades in a vaccine candidate to the naturally occurring viruses in a geographic region has not been established. Although the genetic diversity among HIV-1 strains may be an obstacle to protective immunity, there is little scientific rationale for matching clades to the country from which they emanate. The consensus reached is that the testing of multivalent vaccines should proceed, but practical limitations dictate that vaccine candidates should be representative of clades, rather than country-specific. Extraordinary costs in dollars, man-hours, and time would result from the parallel testing of multiple parallel vaccine prototypes. At the same time, the importance of testing vaccines "relevant" to each country's HIV isolates is evident. Together, these constraints dictate a finite representation of clades in a multivalent vaccine, and the group concluded that a combination clade vaccine—for example, including clades A, B, and C—would cover the majority of HIV-1 infections worldwide.

The efficacy of a multiple-clade versus single-clade HIV vaccine candidate remains an important, unanswered scientific question. The generation of such a multiclade candidate will be of international importance and should remain high on the scientific agenda. Unprecedented international agreement and interagency coordination will be required to advance such candidate into human testing and efficacy trials.

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