ENERGY

Nuclear Waste Management in the United States—Starting Over

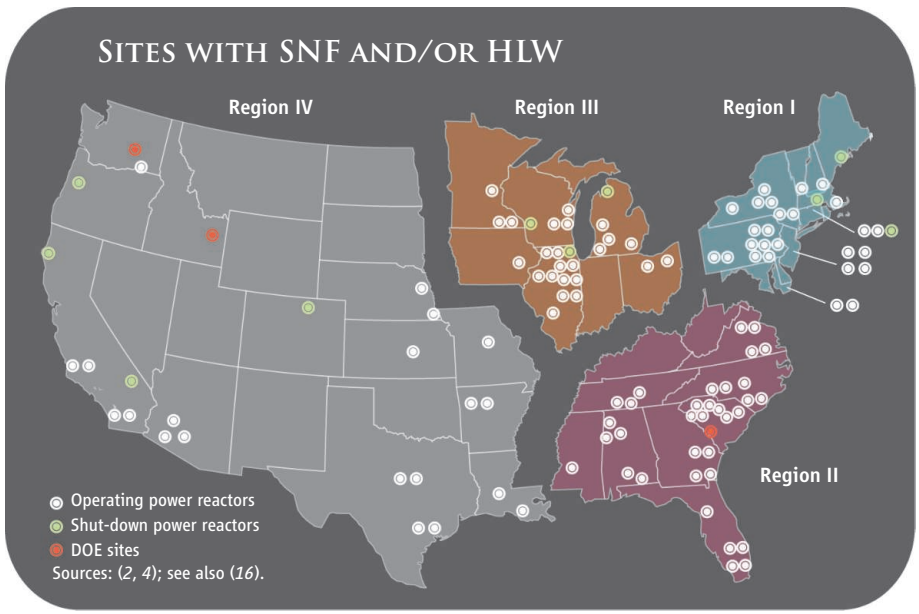
The debate has begun again over the disposition of nuclear fuel and waste.

Rodney C. Ewing[1] and Frank N. von Hippel[2]

The recent action to shelve Yucca Mountain as the potential geologic repository for U.S. "spent" (i.e., no longer usable) nuclear fuel (SNF) and high-level nuclear waste (HLW) (*1*) brings to a close a 30-year effort to develop and implement a policy for nuclear wastes in the United States. Selection by Congress in 1987 of Yucca Mountain in Nevada as the only site to be investigated condemned the United States to pursue a policy that had no backup if Yucca Mountain failed politically or technically.

Abandoning Yucca Mountain will mean that another destination must be found for SNF and the solidified HLW from three U.S. Department of Energy (DOE) sites that had military reprocessing plants and from a pre-1973 commercial reprocessing plant. The country will be left with some combination of three basic options: (i) indefinitely store in 35 states and 75 reactor sites, 10 of which have been decommissioned (*2*–*4*); (ii) consolidate from at least the decommissioned sites at one or more central storage sites; and (iii) restart the process of locating and developing one or more geologic repositories.

Advocates of SNF reprocessing have been energized by the Yucca Mountain decision, but reprocessing would not obviate the need for a geological repository. It only has the political advantage of providing an interim destination for the SNF. A thorough assessment of various proposals to simplify the U.S. radioactive waste problem by separating out long-lived transuranic elements and fission products and fissioning and transmuting them, respectively, found that the efforts would be extremely costly and benefits would be marginal (*5*). Also, the U.S. example would provide civilian cover for other nations interested in acquiring separated plutonium for weapons—which is exactly why the United States reconsidered its pro-reprocessing policy after India's 1974 nuclear test, which used plutonium that had been separated for civilian purposes with U.S. assistance (*6*). France and Japan maintain their commitment to reprocessing, but the United Kingdom is quitting, and a dozen countries that were sending their SNF to France, Russia, and the United Kingdom for reprocessing have not renewed their contracts (*7*).



The U.S. Nuclear Regulatory Commission (NRC) is considering extending on-site storage, as a stopgap measure, on the basis of a decision that SNF can be safely stored in dry casks at reactor sites for up to 60 years after reactor operating licenses expire (*8*). This reflects the reality that storing old SNF in dry casks is a safe short-term option. Few are comfortable, however, with the idea of indefinite storage of SNF and HLW on the surface at about 80 locations.

What Went Wrong?

A geologically complex site. Although there is great attraction to isolating nuclear waste in the arid and remote region of Yucca Mountain, there are unresolved scientific and technical issues. The UO_2 in SNF is not stable under the oxidizing conditions in Yucca Mountain and would convert rather rapidly to more soluble higher oxides. Substantial amounts of water exist in the pores and fractures of the volcanic tuff. The geologic complexity of the Yucca Mountain site, including seismicity and relatively recent volcanism, and the proposed reliance on engineered barriers, notably titanium drip shields to protect the casks from water, make the safety analysis complicated and less than convincing (*9*).

In contrast, two countries that are currently developing underground SNF repositories, Sweden (*10*) and Finland (*11*), have chosen stable granitic host rock permeated with oxygen-depleted water. Their strategy uses copper canisters surrounded by protective bentonite clay, and the estimated failure rate of the canisters is extremely low. France, Belgium, and Switzerland are actively investigating potential repositories in clay. The great age and stability of the granite and clay host rocks increase confidence in long-term predictions of repository performance.

Changing performance standard. There was no U.S. Environmental Protection Agency (EPA) performance standard throughout most of the design process for the Yucca Mountain repository. In September 2008, the belatedly issued new standard extended the proposed regulatory period to 1,000,000 years, a significant change from the earlier proposal of only 10,000 years.

Looking forward, there are two important issues related to the standard. First, the present standard is site-specific, rather than a general requirement of performance and safety. Second, the compliance period is based on

[1]Department of Geological Sciences, University of Michigan, Ann Arbor, MI 48109–1005, USA. E-mail: rodewing@umich.edu [2]Program on Science and Global Security, Princeton University, Princeton, NJ 08542–4601, USA. E-mail: fvhippel@princeton.edu

a recommendation from a committee of the U.S. National Academy of Sciences' National Research Council that it should extend to the time when peak potential risks may occur, generally hundreds of thousands of years hence (*12*). The uncertainties in projecting performance over hundreds of thousands of years are real and cannot be avoided. The use of "quantitative" performance assessment for licensing placed an enormous burden on the demonstration of compliance over such long periods. Yet, Congress's selection of Yucca Mountain prevented the DOE from pursuing strategies that might have reduced the importance of "unknowables," such as locating the repository where volcanism and seismicity are not major factors.

Unreliable funding source. The original Nuclear Waste Policy Act of 1982 provided funding for development of a repository by creating the Nuclear Waste Fund from a tax on electricity generated by nuclear power. However, expenditures for repository development were subject to annual congressional appropriations. Indeed, it is that appropriation process that is being used to put the Yucca Mountain repository on hold.

Management failures. Development of the licensing basis for a site as complex as Yucca Mountain is inherently difficult, but the DOE, with its limited expertise, continual turnover of personnel, changing design requirements, and poor oversight of contractors, allowed the project to grow to a size that was both unnecessary and unmanageable. The department already has spent $13.5 billion in 2007 dollars on researching the site and projects a final cost of $76 billion (not including $20 billion for transportation) for 122,100 tons of SNF (*13*).

Attempt to override local opposition. The decision to proceed with the Yucca Mountain project in the face of strong public and political opposition in Nevada was a mistake. For projects that will take decades to complete, sustained local opposition has every chance of prevailing. The successful siting efforts in Scandinavia have involved local communities in the decision-making process and given them a veto at each stage (*14*). Also, the communities that have finally volunteered to host repositories already have nuclear power plants, are comfortable with nuclear technology, and have an interest in helping to find a path forward from surface storage to underground disposal.

What Should a New Policy Include?

Regional solutions. The DOE should be relieved of the responsibility for management and disposition of used nuclear fuel from commercial nuclear power plants. The states that have the SNF should be provided with the means and motivation for developing acceptable interim storage sites or geologic repositories. The NRC has organized the distribution of nuclear power plants into four regions: northeast, southeast, midwest, and west (see figure, page 151) (*16*). This could also be an appropriate way to divide up the country for locating interim storage facilities or regional repositories. These regions would provide a variety of possible geological media for a repository, including granite, shale, salt, and volcanic tuff.

States within a given region should have primary responsibility for developing solutions unique to their own situations. In some cases, extended on-site or centralized interim storage may be acceptable. Other states or regions may move forward without delay to site and develop a geologic repository. Transportation problems would be greatly reduced because the distances to regional repositories are much shorter than the distance between reactors east of the Mississippi and Nevada. Funding would be provided from the Nuclear Waste Fund (with a current balance of over $20 billion) (*16*) to organizations established by the states or regions or their nuclear utilities for the development of an interim storage facility and/or a geologic repository. Continued funding would come from the 10th-of-a-cent tax on each kilowatt-hour of electricity generated by nuclear power plants in each region. This regional approach for the 104 U.S. reactors would not be too different from the current approach in Europe, where SNF and HLW from ~150 reactors and reprocessing plants is to be moved to a number of national geologic repositories in a variety of rock types. The DOE would remain responsible for management and disposal of low-level, transuranic, and HLW waste generated by nuclear weapons and naval reactor programs.

Local acceptance. In addition to requiring compliance with federal standards and regulations, the local community and state should make the final siting decision. Local communities at potential storage and repository sites should have early and continued involvement in the process, including funding that would allow them to retain technical experts.

EPA regulation. It may be appropriate to leave to the EPA regulation of the environmental impact of the "back end" of the fuel cycle for commercial nuclear power plants. The Waste Isolation Pilot Plan in New Mexico is a successfully operating geologic repository for transuranic waste regulated by the EPA. The EPA should establish a generic, i.e., not site-specific, performance standard for the containment of long-lived radioisotopes in geological repositories.

Each of these proposals will experience stiff opposition. The main goal, however, should be to provide the United States with multiple alternatives and substantial public involvement in an open siting and design process that requires acceptance by host communities and states. International experience suggests that investigation of multiple sites is affordable. In the meantime, dry-cask on-site SNF storage is a relatively safe interim strategy that will give the United States the time required to develop a permanent, long-term solution.

References and Notes

1. The energy section of the Obama Administration's outline of the priorities of its fiscal year 2010 budget concludes, "The Yucca Mountain program will be scaled back to those costs necessary to answer inquiries from the Nuclear Regulatory Commission, while the Administration devises a new strategy toward nuclear waste disposal" (*17*).
2. Operating reactors from NRC, www.nrc.gov/info-finder/reactor/#USMap.
3. Decommissioned reactors with SNF on site from (*4*).
4. National Research Council, *Going the Distance? The Safe Transport of Spent Nuclear Fuel and High-Level Radioactive Waste in the United States* (National Academies Press, Washington, DC, 2006), table 5.2.
5. National Research Council, *Nuclear Wastes, Technologies for Separations and Transmutation* (National Academy Press, Washington, DC, 1996).
6. G. Perkovich, *India's Nuclear Bomb* (Univ. of California Press, Berkeley, CA, 1999), pp. 28 and 30.
7. F. N. von Hippel, *The Costs and Benefits of Reprocessing: Why Reprocessing Persists in Some Countries and Not in Others (Nonproliferation Education Center, Washington, DC, 2009).*
8. NRC, Waste confidence decision update. *Fed. Regist.* **73**, 59551 (2008).
9. A. M. Macfarlane, R. C. Ewing, Eds., *Uncertainty Underground—Yucca Mountain and the Nation's High-Level Nuclear Waste* (MIT Press, Cambridge, MA, 2006), 431 pp.
10. Forsmark, Sweden, SNF disposal site, www.world-nuclear-news.org/WR_Forsmark_for_Swedish_nuclear_waste_0306091.html.
11. Olkiluoto, Finland, repository (4 June 2009); www.world-nuclear-news.org/WR-Approval_for_expanded_Olkiluoto_repository-0406098.html.
12. National Research Council, *Technical Bases for Yucca Mountain Standards* (National Academy Press, Washington, DC, 1995), 205 pp.
13. DOE, *Analysis of the Total System Life Cycle Cost of the Civilian Radioactive Waste Management Program, Fiscal Year 2007* (DOE/RW-0591, DOE, Washington, DC, 2008).
14. Organization for Economic Cooperation and Development, *Public Information, Consultation, and Involvement in Radioactive Waste Management* (OECD Nuclear Energy Agency, Paris, 2003).
15. In addition to sites shown in the figure, SNF is stored at the never-operated GE Morris, IL, reprocessing plant; an additional DOE site with HLW is the decommissioned commercial reprocessing plant, West Valley, NY. There is no SNF or HLW in Alaska, Hawaii, Puerto Rico, or the Virgin Islands.
16. The U.S. Department of the Treasury does not report the balance. The National Association of Regulatory Utility Commissioners (NARUC), in a resolution adopted on 18 February 2009, claims a balance of $22 billion (*18*).
17. Office of Management and Budget, in *A New Era of Responsibilities: Renewing America's Promise* (Government Printing Office, Washington, DC, 2009), pp. 63–65; www.whitehouse.gov/omb/assets/fy2010_new_era/Department_of_Energy.pdf.
18. NARUC, *Resolution in Support of Ensuring the Federal Government Fulfills Its Obligation to Remove Spent Nuclear Fuel from Present Reactor Storage Sites*; www.naruc.org/Resolutions.cfm.

10.1126/science.1174594