The siting of a deep-mined geologic repository requires strong bonds of trust between implementers, regulators, and the host community.

Management of Radioactive Waste
A Socio-Technical Challenge

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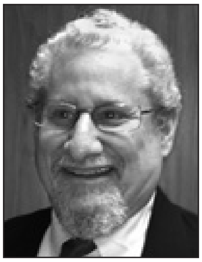

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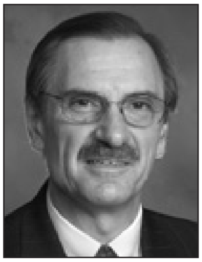

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Few public policy issues rival the management of high-level radioactive waste (HLW) and spent nuclear fuel (SNF) in terms of the controversy it engenders and the demands it places on scientific research and engineering practice. High-activity waste,[2] first produced during the Manhattan Project, still evokes in the general public in the United States and abroad strong negative images that persist, at least in part, because of the failure of repeated

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[1] The U.S. Nuclear Waste Technical Review Board (NWTRB) is an independent federal agency charged with evaluating the technical and scientific validity of efforts by the Secretary of Energy to implement the Nuclear Waste Policy Act, as amended in 1987. The views expressed in this article are those of the authors and are not necessarily the views of the NWTRB.

[2] "High-activity waste" includes both HLW and SNF.

efforts to develop sustainable solutions that are defensible technically and politically.

Overview

High-activity waste is an inevitable by-product of the operation of nuclear reactors designed to generate either electricity or plutonium used in the fabrication of nuclear weapons. Although the final composition of SNF depends on a number of factors, such as its initial enrichment level, reactor type, and burnup level, fuel rods 10-years removed from a reactor typically contain several hundred different isotopic constituents. Collectively, these radionuclides fall into six categories and in the following proportions:

- uranium—95.6 percent (by mass)
- plutonium—0.9 percent
- minor actinides (e.g., neptunium, americium, etc.)—0.1 percent
- long-lived fission products (e.g., iodine, technetium, etc.)—0.2 percent
- short-lived fission products (e.g., strontium, cesium, etc.)—0.3 percent
- stable fission products (e.g., selenium, xenon, etc.)—2.9 percent

About 65,000 metric tonnes heavy metal of spent nuclear fuel are being stored at 78 locations in the United States.

HLW is first produced in liquid form when SNF is chemically processed to remove the preponderance of uranium, plutonium, and minor actinides. HLW contains mostly stable and long- and short-lived fission products, although some actinides may also be present. The liquid is then converted into a solid vitrified form by mixing it in canisters with molten glass. In some countries, such as Sweden, only SNF is disposed. In others, like France, only vitrified HLW is disposed. In still others, like the United States and Germany, both SNF and vitrified HLW are disposed.

The Inventory

In the United States, approximately 65,000 metric tonnes heavy metal (MTHM) of commercial SNF is currently being stored at the 78 sites where 125 large power reactors are operating or have been shut down. Roughly 40,000 MTHM is kept in shielded concrete pools. The remainder is in dry storage casks, which are set on concrete pads located on or close to the reactor sites. An additional 2,000 MTHM of commercial SNF is produced each year.

The U.S. Department of Energy (DOE) also owns a variety of high-activity waste forms, mostly generated as part of the nuclear weapons program. That material, located at four sites, includes nearly 2,500 MTHM of spent fuel and slightly more than 3,100 canisters of HLW. Finally, the federal inventory includes about 27 MTHM of SNF discharged from the reactors of nuclear-powered submarines and aircraft carriers.

Approaches to Long-Term Management

Although most of the radionuclides produced in a reactor pose only minor risks because of their negligible quantities, short half-lives, or insignificant biological effects, high-activity waste, if not managed properly, can seriously threaten human health and the environment. Although complete consensus on the acceptable risk has not been reached internationally, most countries have determined that long-term radiation risk to the public from exposure to high-activity waste should be limited to the level of risk from one or two chest x-rays a year. Most countries have also concluded that this level of protection will have to be sustained for hundreds of thousands of years (NWTRB, 2009).

Over the last half century, the technical community has advanced a variety of approaches for the long-term management of high-activity waste (IRG, 1978):

- shooting the waste into space
- disposing of the waste in the seabed
- burying the waste in the Antarctic ice sheet
- placing the waste in boreholes (several kilometers deep)
- depositing the waste in deep-mined geologic repositories 500 to 1,000 meters below the surface

For the moment at least, there is a strong international consensus about management options: all countries that operate nuclear reactors have focused solely on developing deep-mined geologic repositories.[3] Reflecting this consensus, the Radioactive Waste Management Committee of the Organization for Economic Cooperation and Development held that constructing a repository is "technically feasible" and would provide "a unique level and duration of protection" (NEA, 2008).

As will be discussed below, a variety of repository concepts have been proposed, but they all have some common features. The high-activity waste is packaged, either away from or at the repository site. The repository itself is built by excavating ramps or shafts that lead to locations in the geologic formation where the waste is to be emplaced. The waste packages are delivered in a shielded vehicle below ground and are either emplaced in vertical boreholes carved out of the host rock or are simply set on the drift (tunnel) floors. Once emplacement operations are complete, the drifts are backfilled, and the ramps or shafts are sealed. Figure 1 shows a representative layout of a deep-mined geologic repository.

As yet, no country has put a deep-mined geologic repository for high-activity waste into operation. Moreover, with the exception of Finland, every country that has attempted to site such a facility has experienced one or more setbacks that have necessitated substantial organizational and policy changes. Finland, along with Sweden and France (both of which recovered relatively rapidly after initial programmatic interruptions), has the most advanced schedules for managing high-activity waste. All three expect to commence disposition operations sometime between 2020 and 2025.

In the United States, where efforts to develop a repository began more than four decades ago, the situation is still unsettled. In 2002, Congress approved the siting of a deep-mined geologic repository at Yucca Mountain in the Nevada desert. In 2008, DOE submitted an application to the U.S. Nuclear Regulatory Commission (NRC) asking for approval to construct a facility.

Subsequently, the Obama administration announced that the Yucca Mountain repository was "not a workable option" and sought to withdraw the license application. At the same time, the Secretary of Energy appointed a Blue Ribbon Commission on America's Nuclear Future (BRC or the Commission) to recommend an alternative path forward. In its final report, published in January 2012, the BRC calls for, among other things, the "timely" development of a repository based on a "consent-based" process (BRC, 2012). At the time of this writing, however, the fate of the recommendations is unclear. The NRC licensing proceeding for the Yucca Mountain repository has been suspended pending the outcome of a court case and future congressional appropriations.

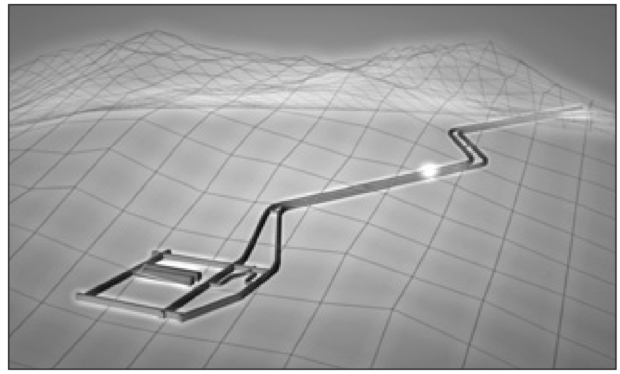

FIGURE 1 Schematic illustration of a repository for high-activity waste. Source: PURAM. Available online at *http://www.rhk.hu/en/photo-gallery*. Accessed on April 16, 2012.

Repository Concepts

In 1955, the National Academy of Sciences (NAS) sponsored a study to evaluate options for isolating and containing high-activity waste until radioactive decay had decreased the toxicity of the materials. Although the study committee noted that additional research was still needed, it concluded that "radioactive waste could be disposed of safely in a variety of ways and in a number of sites in the United States" and that "disposal in salt [was] the most promising method for the near future" (NAS, 1957, pp. 16–17).

Repositories in Salt

Salt is considered a particularly attractive host rock for a deep-mined geological repository because (1) its presence implies the absence of flowing water, which is the predominant vehicle for transporting to the environment materials that are eventually released from high-activity waste, (2) fractures arising in a salt formation are self-healing, and (3) the high thermal conductivity of salt would permit the construction of a facility with a small footprint. In addition, for a repository developed in a salt formation, the geology alone is sufficient to isolate and contain high-activity waste.

[3] Management of high-activity waste requires a tightly integrated system capable of transporting the material from the sites where it is generated to, perhaps, plants where it is processed to extract residual fuel materials from the SNF, then to, perhaps, facilities where it might be stored temporarily, and finally to a deep-mined geologic repository for permanent disposal. This article focuses on the final step in the management process.

The NAS study was so influential that, during the 1960s and early 1970s, plans in the United States for disposing of high-activity waste were focused solely on developing a repository in salt. The German waste management program, also influenced by the study, has been focused on a salt repository since the 1970s.

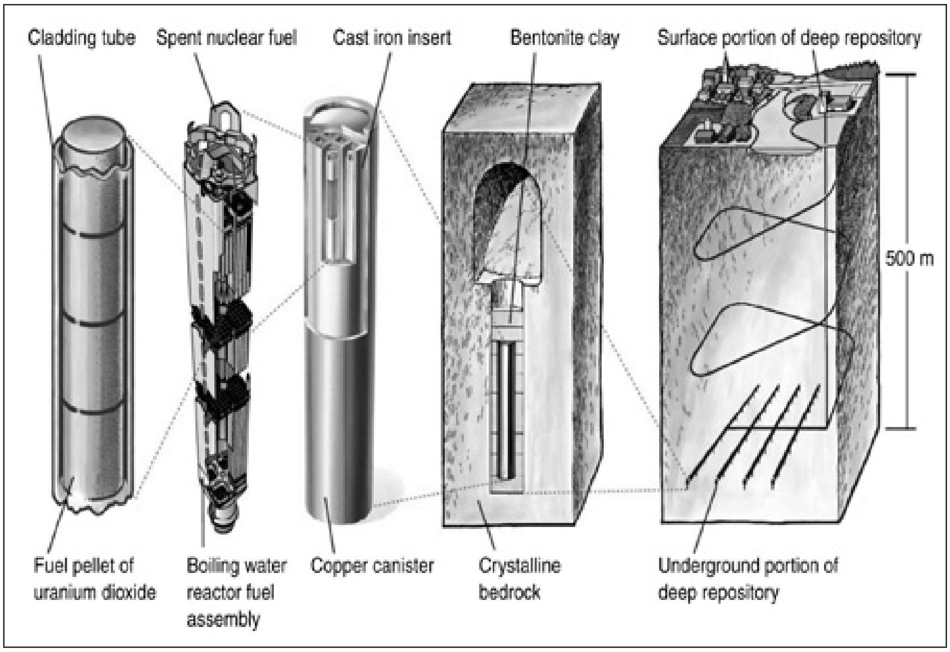

FIGURE 2 Design concept for a deep-mined repository in crystalline rock. Source: SKB. Available online at *http://www.skb.se/Templates/Standard____24109.aspx.* Accessed on April 16, 2012.

Repositories in Clay Deposits

Many countries, however, do not have salt formations within their borders suitable for constructing a repository.[4] Therefore, some have turned to indigenous clay deposits as an alternative. For example, boom clay in Belgium, argillite in France, and opalinus clay in Switzerland have been identified as suitable host rocks for a deep-mined geologic repository. Clays can isolate and contain high-activity waste because (1) water moves extremely slowly through those strata, (2) clays can have a high sorptive capacity for radionuclides, and (3) fissures or fracture planes in the rocks close by themselves over time. Notably, like a salt repository, a clay repository would rely almost completely on geology to isolate and contain high-activity waste for millennia.[5]

Repositories in Crystalline Rock

A different approach has been taken by the Swedish and Finnish waste-management programs, and possibly by programs in Canada, Japan, and China. In their repository concept, waste isolation and containment would depend on both geology (natural barriers) and man-made structures (engineered barriers). Both kinds of barriers would be necessary for repositories in crystalline host rocks, such as granite or gneiss, which are pervasive in those countries.

For a repository in crystalline host rock (Figure 2), high-activity waste would first be loaded into a cylinder fabricated from cast iron or a similar material, which is not intended to provide long-term protection against corrosion. The package would then be lowered into an elemental-copper canister. The repository itself would be located in crystalline formations where the electrochemical, pH, and solute properties of the circulating groundwater would not challenge the structural integrity of the canister. The canisters would be emplaced in oversized shallow boreholes in the floor of the drifts, which would then be filled with blocks of bentonite clay, which can slow the movement of groundwater and capture high-activity waste that might migrate from the canisters.

A Repository in Tuff

A totally different concept evolved for Yucca Mountain, where the host rock is tuff (consolidated ash ejected from a volcano millions of years ago). Unlike any other site under consideration, the repository horizon at Yucca Mountain is *above* the water table. Because of this, it was initially believed that the tunnels would remain "dry," making robust waste packages superfluous.

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[4] The established international principle is that each country should dispose of its high-activity waste within its own borders. Over the years, the possibility of developing a multinational repository has been explored, but so far, the idea has not matured beyond the talking stage.

[5] In both concepts, the packages holding the high-activity waste are expected to isolate and contain the material for only several hundred years.

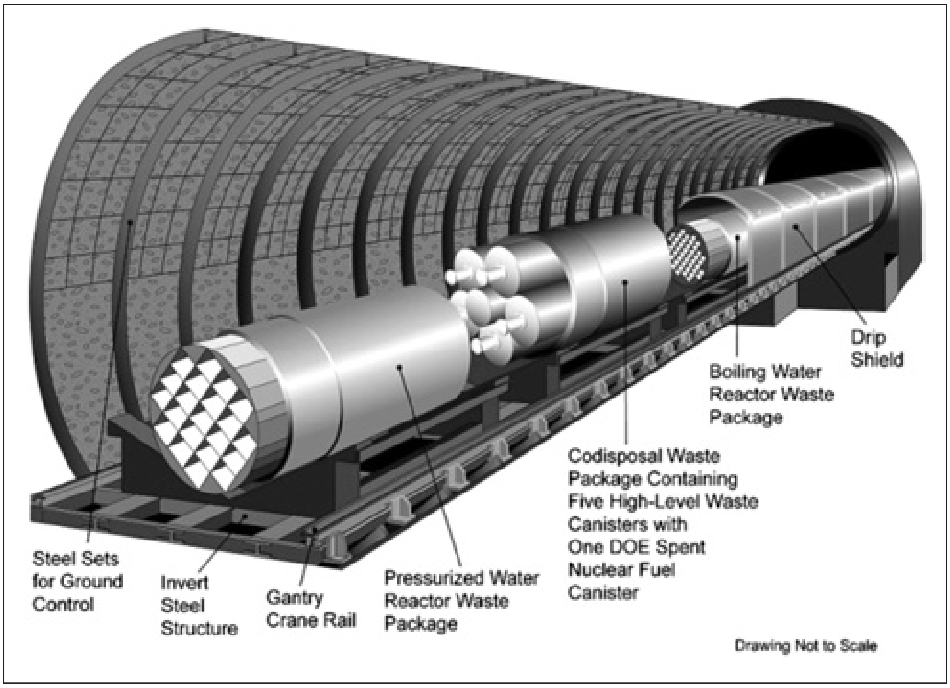

FIGURE 3 Design concept for the proposed Yucca Mountain repository. Source: DOE. Available online at *http://esmeraldanvnuke.com/yucca.html.* Accessed April 16, 2012.

As the project advanced, however, site investigations revealed that water could seep into the drifts. Thus in the oxidizing environment that would surround the horizontally emplaced carbon-steel waste packages, corrosion suddenly emerged as a serious potential problem. To address this concern, a corrosion-resistant, nickel-based alloy was substituted for carbon steel as the material for the outer shell of the waste package, and drip shields made of titanium were introduced to deflect water that might seep into the drifts from above (Figure 3).

In the Yucca Mountain repository concept, at least according to DOE, the engineered barriers are designed to be robust enough to isolate and contain the high-activity waste almost indefinitely. Any radionuclides that eventually escape from the packages would move slowly, held up by natural barriers above and below the water table.

Attitudes and Beliefs

The recent turbulence surrounding the proposed repository at Yucca Mountain is only the latest instance in which public and political opposition have forced national waste-management programs to reassess their approaches and goals.

During the late 1980s and through the early 1990s, programs in a number of other countries also encountered formidable obstacles. In Canada, a proposed repository was debated at a series of public hearings, and Government ultimately concluded that the concept had achieved technical, but not social, acceptance. In Sweden, attempts to investigate potential sites in several communities were stopped when citizens blockaded access roads. In France, efforts to evaluate potential sites not only enflamed local communities but also triggered demonstrations nationally. In the United Kingdom, a proposal to construct a laboratory to conduct research underground failed to receive local "planning permission," a decision that was later upheld by Government.

Public Perceptions of Risk

Cognitive psychologists and specialists in public opinion have produced a body of findings that provide insights into why the management of high-activity waste has elicited such strong reactions. These scholars have concluded that the general public perceives the risk of a technology or activity by evaluating—either consciously or subconsciously—more than a dozen factors.[6] Consider one of them, familiarity. All other things being equal, the more an object or event is seen as *unfamiliar*, the greater the perceived risk (Slovic, 1987).

One study compared public perceptions of the risk of 30 technologies and activities and found, not surprisingly, that the risk of radioactive waste was perceived to be relatively high (Hinman et al., 1993). In fact, it evokes the strongest feelings (other than toward nuclear accidents and war) of uncontrollability, dread, and involuntariness. As one historian concluded, matters

[6] The factors most often studied are: voluntary/involuntary; chronic/catastrophic; calm/dread; certainly not fatal/certainly fatal; known to be exposed/not known to be exposed; immediate/delayed; known to science/unknown to science; controllable/not controllable; and familiar/unfamiliar.

nuclear strike an especially discordant bell for the public (Weart, 1988).

Importantly, the general findings about risk perceptions of radioactive waste in the United States are similar to perceptions in other countries. In the comparative study just mentioned, radioactive waste was found to produce almost exactly the same strong feelings of uncontrollability and dread in the Japanese public. Research into perceptions of risk held by the general public in Sweden, France, and the Netherlands is also strongly consistent with the conclusions about the perceptions of Americans (e.g., Sjöberg, 2003, and Wiegman et al., 1995).

Perhaps more revealing were the results of a research project carried out under the auspices of the European Commission (EC, 2008). More than 26,000 residents of the 27 member states of the European Union were interviewed about their attitudes toward the management of radioactive waste. As part of the survey, individuals were asked whether they agreed or disagreed with the following statement, "There is no safe way of getting rid of high-level radioactive waste." Although one might quibble with the wording, the unambiguous results cannot be explained away simply by advancing a methodological critique. Overall, 72 percent of the respondents either totally agreed or tended to agree with the statement. Only 14 percent disagreed.

In a 2008 survey of 26,000 EU citizens, 72 percent agreed that "there is no safe way of getting rid of high-level radioactive waste."

A breakdown of the aggregate results of the study yields valuable insights. In Finland, France, and Sweden—the three countries with the most advanced repository programs—82 percent of those surveyed concurred with the statement. Lithuanians, Hungarians, Latvians, and the Dutch were most inclined to disagree, although a majority in each of those countries did agree.

In addition, risk perceptions did not vary by age, education level, or by the respondents' level of information about radioactive waste. And, contrary to expectations, risk perceptions were not strongly influenced by political philosophy. Of the people who identified with right-wing ideologies, 71 percent agreed with the statement. Of those who identified with left-wing ideologies, 77 percent agreed.

Only one significant demographic difference was reported. Fewer individuals who were in favor of nuclear energy production *totally* agreed with the statement than those who opposed nuclear energy production (36 versus 50 percent). However, when these numbers were added to the percentages of respondents who *tended* to agree, the sums were comparable.

The general public's perceptions of risks associated with radioactive waste (at least as imperfectly measured by opposition to the siting of a repository) may or may not change over time. In the case of the Waste Isolation Pilot Plant (WIPP)[7] located in New Mexico, attitudes became markedly more favorable as the public in that state gained experience with the facility's operation. Opposition fell from nearly 60 percent in 1995 to 35 percent in 2000 (Jenkins-Smith et al., 2009). By contrast, for the last quarter century, public disapproval in Nevada of the proposed repository at Yucca Mountain has never dropped below the 65 to 70 percent range.

Technical Specialists' Perceptions of Risk

Risk perceptions of technical specialists typically differ from the perceptions of the general public, although not in easily predictable ways (Bostrom, 1997). The few systematic studies that have been undertaken suggest that experts perceive the risks associated with managing high-activity waste to be significantly lower than the general public does (Flynn et al., 1993). For example, whereas 60 percent of the general public in a national survey disagreed with the statement that "buried waste will be contained in the waste site so that contamination of underground water supplies will not occur," only 14 percent of those surveyed at a meeting of the American Nuclear Society dissented. But even technical experts do not perceive the risks uniformly. The risks perceived by medical researchers, for example, are 50 percent higher than by physicists (Barke and Jenkins-Smith, 1993).

From the perspective of those responsible for developing a system for managing high-activity waste,

[7] WIPP is only authorized to accept transuranic-contaminated waste from the U.S. defense complex, not the high-activity waste that is the focus of this article.

information about risk perceptions may only be of academic interest. However, attitudes about managing radioactive waste can be translated directly into public policy, at least in the United States and some European nations, when initiatives and referenda are voted on. They can also be indirectly translated into public policy if the issue becomes highly salient in political campaigns, as it did in Sweden and Germany.

The Issue of Trust

Research suggests that risk perceptions of the development of a deep-mined geologic repository have more nuanced implications. Over the last 20 years, a significant body of literature has emerged linking risk perceptions with trust in the institutions charged with managing those risks (e.g., Cvetkovich and Löfstedt, 1999).

The dominant view is that trust affects beliefs, and so the more trustworthy the institution (all other factors being equal), the more perceptions of risk will be diminished (Flynn et al., 1992). As a practical matter then, if the implementer and regulator of national waste management programs can sustain a high level of trust, the chances of opposition being mobilized simply because of a perceived high level of risk tend to be lower. The converse also holds true.

Alternatively, the direction of the causal arrow can be reversed, that is, risk perceptions can influence the level of public confidence in the managing institutions.[8] The implications of this reversal might be far-reaching. If the risk of managing high-activity waste were perceived to be low, then the public would be more likely to trust the scientific and technical judgments of implementers and regulators.[9] The converse also holds true. We return to this point below.

Siting a Deep-Mined Geologic Repository

Given deep-seated public concerns about the risks associated with managing high-activity waste, it is hardly surprising that siting efforts worldwide have generally been unsuccessful. Since the 1970s, roughly two dozen initiatives have been launched to identify technically and politically suitable sites for deep-mined geologic repositories. As noted above, only three of those efforts are still on track (NWTRB, 2011).

[8] Most likely, perceptions and trust are reciprocally related.

[9] This perspective is developed in Kunreuther and Easterling, 1995.

Technical Obstacles

Sometimes the obstacles have been technical. For example, in the late 1960s, the U.S. Atomic Energy Commission began investigating a salt site near Lyons, Kansas. Although this study provoked intense political opposition at the state level, the project was ultimately doomed by the investigators' inability to account for the substantial amount of water that was routinely used to solution-mine the mineral.

In the mid-1990s, the French implementing organization, ANDRA, sought volunteer communities to host two underground research laboratories (URLs), one situated in clay and the other in granite. Two communities stepped forward. However, when the Committee of National Evaluation, the French technical oversight body at the time, reviewed the geology of each site, it concluded that the proposed granite site was too complex to be adequately characterized.

Risk perceptions are linked to trust in the institutions charged with managing them.

Political Obstacles

More frequently, the obstacles to siting have been political. The controversies that adversely affected programs for managing high-activity waste in Canada, Sweden, France, the United States, and the United Kingdom have already been touched upon. The situations in Germany and Japan, however, illustrate how intense public reactions can effectively paralyze a country's waste-management program for decades.

More than 30 years ago in Germany, a salt site was identified near the town of Gorleben in Lower Saxony that might be suitable for development as a deep-mined geologic repository. Experiments were conducted and seemed to support the view that high-activity waste could be isolated and contained there for millennia. Although investigations continued, opponents at the national level maintained that the process for selecting the site had been flawed. That opposition delayed any final decision about the suitability of the site for many years.

The formation of a governing coalition in 1998 between the Socialist and Green parties effectively derailed consideration of the site for almost another 10 years. But with the return to power of the Christian Democratic Party in 2010, the way seemed paved for a determination that the Gorleben site was suitable, and work on the project to develop a repository was resumed. However, in the aftermath of the Sendai tsunami in Japan that disabled the Fukushima-Daiichi reactors in 2011, Germany is again revisiting its repository-siting strategy.

Years of interaction between implementers and potential host communities can create strong bonds of social trust.

Even before the tsunami struck, the waste-management program in Japan was mired in controversy. In 2002, the implementing organization adopted what appeared to be the "best-practice" approach for selecting a repository site. Very general technical criteria were published specifying the geologic features that *automatically disqualified* a site from consideration.

Volunteer communities were sought; they only had to agree to paper and desk studies to ascertain whether nearby formations *might* be suitable. In addition, substantial benefit packages were offered to communities that agreed to the evaluations, and the communities could opt out of the process up until the time that significant work underground had commenced. Still, only one mayor was prepared to volunteer. And then, almost immediately, prefecture governors objected, and the mayor was recalled. No other community leader has stepped forward since.

The situation is not entirely bleak, however, at least in Europe. After years of patient interaction with local communities, implementers in Finland, France, and Sweden have selected potential sites for deep-mined geologic repositories, and leaders of the chosen districts have embraced the prospect of hosting such facilities.

Lessons Learned

Lessons from all of these siting experiences have not been lost on the directors of national waste-management programs.[10] Siting efforts now under way in Canada and the United Kingdom reflect these lessons, and the recommendations by the BRC in the United States are in line with this "new" understanding:

- *Potential host communities must at least acquiesce to site investigations*. Carlsbad, the closest town to WIPP, aggressively lobbied for the facility. The Meuse and Haute-Marne districts in France welcomed the construction of a URL, knowing that if the argillite there was suitable, a full-scale repository might be constructed nearby. The town of Eurajoki in Finland and the municipality of Osthammar in Sweden responded positively to invitations from the two national implementers, Posiva and SKB, respectively.
- *Implementers must work intensively to engage potential host communities by establishing a strong, long-term local presence*. DOE required that officials involved with the WIPP project and researchers from national laboratories move to Carlsbad, New Mexico. In France, a Local Information and Oversight Committee has been established so that representatives of communities in the Meuse and Haute-Marne districts can continuously interact with ANDRA. In Sweden and Finland, the potential repository host communities had already become familiar with the implementers, because they (or their consortium members) had operated nuclear reactors at those sites for a long time. In each case, however, interactions were intensified when the municipalities began to be considered as potential locations for deep-mined geologic repositories.
- *Potential host communities must have a realistic, practical way to withdraw from the siting process*. The state of New Mexico was a full partner in negotiating the terms of the Land Withdrawal Act that permitted WIPP to operate. In France, the districts in question willingly accepted the prospects of hosting a deep-mined geologic repository when they volunteered to host the research laboratory. In Finland, Eurajoki's consent was required before the Parliament could pass the "decision-in-principle" to site the proposed geologic repository. In Sweden, Osthammar must agree to the granting of a license by Government. If the municipality should decide for some unexpected

[10] The Japanese experience is typically discounted and dismissed as a deviant case, even though Japan's federal structure makes it the most relevant example for informing future siting initiatives in the United States.

reason to exercise its veto power, the veto could, in theory, be overridden by Government. As a pragmatic matter, however, national culture and historical precedents would make such an override highly unlikely.

One consequence of implementers engaging potential host communities in a sustained and serious way appears to be the formation of strong bonds of social trust. The existence of those bonds is documented in both anecdotal evidence and systematic public opinion polls. For instance, from 2000 to 2005, mean social trust rose significantly among both men and women in Osthammar (Sjöberg, 2004, 2006). At the same time, mean perceived risk associated with the management of high-activity waste declined among women, even though the risk perceived by men, already very low, did not change. Attitudes toward a potential repository improved markedly among both men and women.[11]

Site Characterization and Regulatory Compliance

Once the implementer has at least tentatively selected a site for a deep-mined geologic repository, the characterization process accelerates. Considerable information can be derived from experiments in a URL, such as those established in France and Sweden. But, at some point, site-specific data must be gathered. In some countries, including France and Sweden, as well as at WIPP in the United States, only surface-based testing is allowed until formal approval has been obtained from the authorities to break ground. In others, such as Finland and in the United States at Yucca Mountain, underground investigations were allowed to begin at an early stage.

Designing a research strategy for verifying the suitability of a site and ultimately developing arguments about the long-term safety of a repository is always time consuming and may, in some cases, be simpler in theory than in practice. For repositories where natural barriers will mostly isolate and contain the high-activity waste (e.g., salt and clay), the key parameters to be evaluated are well understood. How, for instance, does salt respond to heat? How permeable is the clay?

For repositories where engineered barriers will contribute importantly to long-term repository performance, characterization must include assessments of *interactions* between the man-made and geologic components of the repository system. For a repository situated in a granitic formation, understanding some of those interactions may not be especially challenging. What, for example, is the permeability of the bentonite? However, other interactions may be harder to evaluate. For example, will the groundwater suffusing the repository corrode the copper canisters?

In a repository situated in tuff, like the proposed Yucca Mountain facility, understanding the interactions between the two types of barriers is probably even more difficult. How much water will infiltrate the drifts? What will its chemical composition be? Will the drip shields and nickel-alloy waste packages be vulnerable to attack either by dripping water or deliquescent salts that may form on the surface of the waste packages? What will be the source term if the engineered barriers are compromised?[12]

Regardless of the design concept, the implementers of national waste-management programs face similar scientific and technical challenges in projecting the behavior of repository systems for hundreds of thousands of years. Although laboratory experiments and *in situ* testing produce valuable data, the long-term performance of a deep-mined geologic repository can only be projected using complex, interdependent computer-based models of various scenarios that could affect how a repository might behave.

Significant unresolvable uncertainties are bound to be present in any projection of repository performance.

Depending on the regulatory philosophy in different countries, the models may be deterministic, probabilistic, or a combination of the two. The assessment of the modeling by regulators, and, in some nations, by Government, will determine whether the deep-mined geologic repository can be constructed and operated.

[11] Although the Swedish study did not examine the causal connection between social trust and perceived risk, the findings are consistent with the American study, cited above, which did model the relationship between the two variables.

[12] "Source term" refers to the rate of release and the composition of radioactive materials that eventually flow from the waste packages.

It is worth noting that trust and risk perceptions may affect how the regulatory process plays out. For example, if perceptions of risk can be lowered, key stakeholders may be more inclined to trust the scientific and technical judgments of both implementers and regulators. Such confidence may be a crucial ingredient in a challenging regulatory process, because significant unresolvable uncertainties are bound to be present in any projection of repository performance.

Conclusion

Few public policy issues rival the management of high-activity radioactive waste in terms of demands on scientific research and engineering practice and the controversy they engender. After decades of dedicated work in more than a dozen nations, evidence is beginning to increase confidence that "solutions" can be found to this pressing environmental problem. More important, lessons are being learned about how to design social processes that lead to technically and politically defensible outcomes. Given this progress, and because the stakes are so high, it would be unfortunate if temporization displaced action.

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