

Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries

A Report to Congress and the Secretary of Energy

April 2011

UNITED STATES
Nuclear Waste Technical Review Board

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UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
Arlington, VA 22201–3367

April 15, 2011

The Honorable John A. Boehner
Speaker of the House
United States House of Representatives
Washington, DC 20515

The Honorable Daniel K. Inouye
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Steven Chu
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Boehner, Senator Inouye, and Secretary Chu:

The U.S. Nuclear Waste Technical Review Board submits this report, *Experience Gained From Programs to Manage High-Level Radioactive Waste and Spent Nuclear Fuel in the United States and Other Countries*, in accordance with provisions of the 1987 amendments to the Nuclear Waste Policy Act (NWPA), Public Law 100-203, which directs the Board to report its findings and recommendations to Congress and the Secretary of Energy at least two times each year. Congress created the Board to perform ongoing independent evaluation of the technical and scientific validity of activities undertaken by the Secretary of Energy related to implementing the NWPA.

This report explores the efforts of 13 nations to find a permanent solution for isolating high-level radioactive waste (HLW) and spent nuclear fuel (SNF) generated within their borders. It builds on information in the Board's 2009 *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. Unlike the earlier document, however, this report describes the programs and their histories and discusses inferences that can be drawn from their experiences. We submit the report to provide contextual information for Congress and the Secretary as options are considered for managing HLW and SNF in the United States.

The Board looks forward to continuing to provide useful independent technical and scientific information to Congress and the Secretary that can be used to inform the decision-making process.

Sincerely,

{signed}

B. John Garrick
Chairman

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Acknowledgments

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Any errors that remain are the responsibility of the Board.

Credits for Cover Photographs (from back to front, left to right)

Swedish Nuclear Fuel and Waste Management Corporation: CLAB
U.S. Department of Energy: Aerial view of Yucca Mountain
French National Agency for Radioactive Waste Management: Underground Research Laboratory at Bure
Posiva Oy (Finland): Waste package
U.S. Department of Energy: Exploratory Studies Facility at Yucca Mountain

Executive Summary

This report explores how 13 nations are carrying out efforts to find a permanent solution for isolating and containing high-level radioactive waste (HLW) and spent nuclear fuel (SNF) generated within their borders. Many forces shape how those efforts are designed and implemented. Some of the forces are technical, including choices made about what reactor technology to adopt and about what nuclear fuel cycle to pursue. Others are social and political in nature, including how concerns about intergenerational equity should be addressed and what pace should be followed in implementing a long-term management option. Importantly, the interdependencies, both subtle and overt, between the technical, social, and political forces are inescapable. Because of those interdependencies, what characterizes the national programs most notably is their *variety*.

This report attempts to detail that variety. It builds on the information contained in the U.S. Nuclear Waste Technical Review Board's (NWTRB) *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel* (NWTRB 2009). Compared with the earlier document, however, this report is more descriptive and considers the history of national programs.

Process Considerations

All national programs keenly recognize today that the long-term management of radioactive waste is a complicated *socio-technical* problem, with the social dimension playing an integral role in determining the shape and the ultimate success or failure of a project (see, for example, IAEA 2007). Decisions in all countries about the long-term management of HLW and SNF were initially made by a small group of technical experts, industry representatives, legislative leaders, and government officials. As nuclear power and nuclear waste (and their connection) arose in the mid-1970s as public issues, the need to broaden opportunities for public engagement became clear. Two patterns emerged. First, traditional participatory mechanisms typically were mated with those that were novel and more innovative, such as creating partnerships with potential repository host communities. Second, especially as difficulties arose, many national programs came to recognize the importance of the latter mechanisms and began to rely on them.

Attention has been drawn during the last 20 years to one factor, variously referred to as social or institutional trust that appears to play an important, and perhaps even a decisive, role in determining the effectiveness and perhaps the legitimacy of public-engagement processes (Cvetkovich and Löfstadt 1999; IAEA 2007). Some national programs have come to merit considerable trust and confidence. Other national programs, such as the one in the United States implemented by the U.S. Department of Energy (DOE), either have lost public trust and confidence or seem never to have merited it at all (Carter 1987; Herzik and Mushkatel 1993; SEAB 1993).

In the last decade as well, attention has been drawn to what is presented as a new approach to making choices about the long-term management of HLW and SNF (NEA 2004a; NAS 2003; NWMO 2005). Often referred to as "adaptive management" or "staged decision-making," this approach is actually a refinement of the incremental decision strategy first detailed in the 1950s (Lindblom 1959). At the theoretical level, it is hard to find fault with a decision-making strategy that seems to promise so much. As a more practical matter, however, it is still unclear whether this strategy can be any more successful than earlier efforts in overcoming local and state opposition to specific siting decisions, whether it can be implemented, and even whether it *should* be implemented (Lee 1999).

Development, Assessment, and Adoption of Waste-Management Options

Over the years, national programs have explored a variety of options for the long-term management of HLW and SNF. These options have included the following (IRG 1978):

- Deep-mined geologic disposal
- Burying the waste in deep-sea sediments
- Placing the waste in deep-drilled boreholes
- Partitioning and transmuting the long-lived radioisotopes
- Shooting the waste into space
- Storing the waste indefinitely either above or below ground in a retrievable fashion.

Almost universally, policy-makers have determined that disposal of HLW and SNF in a deep-mined geologic repository is the preferred option for protecting human health and the environment for thousands of years.

In some countries, such as the United States and Germany, that choice was never formally reconsidered. National waste-management programs in other countries, such as France and Canada, also initially chose the geologic disposal option but were compelled by public pressure to evaluate other options explicitly. Although 11 out of the 13 nations considered in this report are officially committed to developing deep-mined geologic repositories as the preferred option for the long-term management of their HLW and SNF, the pace of the development process varies considerably.

Institutional Arrangements for Executing Waste-Management Programs

Every national waste-management program must address two interrelated questions: Which organizations should be assigned the responsibility for executing which parts of the program, and how will the program be funded? The 13 countries have answered the questions in strikingly different ways.

At least two institutions are involved in executing national waste-management programs. The implementer is responsible for developing a safety case, identifying and characterizing candidate sites, and designing, building, and operating the deep-mined geologic repository. The regulator determines whether the approach advanced by the implementer is acceptable. Very early on in some countries, such as the United States, the implementer and the regulator were the same organization. Now there is general agreement that the two institutions should be independent of each other, even if, as in Germany and Japan, they are housed within the same government bureaucracy (see, for example, NEA 2009).

In all 13 national waste-management programs, the regulator is a governmental organization. The current organizational form of the implementer, however, varies considerably across those countries. Some have opted to use a traditional government agency. In other countries, the implementer is a private corporation. The organizational form of the implementer in eight of the 13 the national programs examined in this report has remained the same. For the rest, significant changes often have occurred, typically away from government and towards hybrid or private organizational forms. For many of the significant shifts over time, the root cause appears to be a response to major programmatic challenges.

Both the variety and the evolutions of the implementers' organizational forms seem to demand an inquiry into a question: Which form is best? A simple analysis that tries to associate particular forms with the completion of repository-development milestones produces no clear-cut conclusions: Of the four national programs furthest along, one has been implemented by a government agency (United States), one by a government-owned public service agency (France), and two by private corporations (Finland and Sweden). Advocates of particular forms have supported their choices mostly with impressionistic and unsystematic claims that have not been put to any objective test (Thomas 1993).

Two main approaches toward financing have been adopted by the 13 countries examined in this report. First, special funds have been set up in Canada, Finland, France, Spain, Sweden, Switzerland, and the United States to which waste producers or the consumers of nuclear-generated electricity contribute each year. Second, the expenses incurred by waste-management programs in China, Germany, and the United Kingdom are paid annually out of general government revenues. Although special funds have been established in Belgium, Japan, and the Republic of Korea, the expenses of their current waste-management programs are not covered by the funds but by general governmental revenues.

Technical Basis for Developing Disposal Concepts and Supporting a Safety Case

In all countries, the implementer has the responsibility for designing a disposal concept that describes a repository system comprising natural and engineered barriers. In most countries, limitations imposed by the geology constrain which disposal concepts can be considered. The implementer typically ends up focusing on one particular geologic formation because of its prevalence or because other formations either are unsuitable technically or cannot be developed because of land-use conflicts. Once a host rock has been chosen, the implementer considers the hydrogeologic environment and determines what, if any, engineered barriers are appropriate as well as how the repository system as a whole will be designed. The implementer is then expected to advance its safety case, a set of arguments and analyses demonstrating why its proposed deep-minded geologic repository will isolate and contain HLW and SNF for as long as society demands. (Various standards and regulatory requirements reflect those demands.) There is broad scientific agreement that deep-mined geologic repositories can be constructed in a wide variety of host-rock formations and hydrogeologic environments, including in salt, crystalline rock such as granite, different clay formations, and unsaturated volcanic tuff.

Substance and Adoption of Health and Safety Standards and Regulations

Health and safety standards and regulations serve two purposes. They record society's views about what constitutes acceptable risk, and they establish mechanisms for certifying that an implementer's plan to develop a deep-mined geologic repository can, with a high degree of confidence, satisfy those requirements. All of the 13 national waste-management programs have put in place at least a rudimentary regulatory regime.

Regulators determine what specific standards need to be met. Typically, they must decide on the length of the compliance period, the time over which the repository is expected to satisfy the protective standards. Regulators originally chose compliance periods of several thousand years. The national programs in Belgium, France, Germany, Sweden, Switzerland, and the United States have selected compliance periods of at least 100,000 years and, in most of those cases, as much as 1,000,000 years. In the United Kingdom, the regulator requires the implementer to choose a compliance period and justify its choice. Further, they impose dose constraints or risk limits or some combination of the two. Increasingly national waste-management programs have converged on similar dose constraints and risk limits, at least for the first few thousands of years that a repository is expected to isolate and contain HLW and SNF. Dose constraints vary between 0.1 and 0.3 millisieverts per year. Risk limits vary between a probability of 10^{-5} and 10^{-6} per year that death or serious health effects will arise over the course of the lifetime of an individual from exposure to radionuclides released from a repository.

Regulators decide how prescriptive their requirements should be. Those choices have produced considerable variation in how much direction the regulators provide. In some national programs, most notably the one in the United States, the rules are quite detailed, laying out specific requirements that the implementer must fulfill in order to get permission to construct or operate a deep-mined geologic repository. Finally, national programs differ in terms of how compliance with the standards is to be demonstrated and what the requirements for demonstration are.

National programs typically have put health and safety regulations into place *after* the implementer has begun to formulate its safety case or to identify candidate sites for a deep-mined geologic repository but *before* specific sites have been chosen. Some interested and affected parties contend that revising regulations *after* a final site already has been selected for a deep-mined geologic repository is inappropriate if the change process is not well explained and supported.

Strategies for Identifying Candidate Sites for a Deep-Mined Geologic Repository

President Jimmy Carter's Interagency Review Group on Nuclear Waste Management (IRG) observed that site-selection strategies for a deep-mined geologic repository necessarily involve passing candidates through what is, in effect, two distinctly different "filters." On the one hand, detailed and quantitative technical requirements have to be met. On the other, sites could be disqualified because of considerations such as the "lack of social acceptance, high population density, or difficulty of access." The two filters could be applied in any order. In the IRG's view, at least, although the suite of sites eventually selected might be different, depending on the order in which the filters were applied, "equally suitable sites should emerge from either approach" (IRG: 1979, 80; 81). Over the years, the United States and other nations have initiated roughly two-dozen efforts to identify or to create processes for identifying potential repository sites. What is noteworthy is how varied those efforts have been.

Part of the variation stems from how the technical filter is constructed. In some cases, efforts to identify candidate sites have focused from the beginning on specific host-rock formations. The choice of those formations has been dictated either by constraints imposed by a country's geology or land-use patterns, by a view that particular host-rock formations possess distinctive advantages in terms of isolating and containing HLW and SNF, or by a combination of these rationales. In other cases, efforts to identify candidate sites cast the net more broadly by enumerating generic qualifying and disqualifying conditions. Qualifying conditions must be satisfied for a candidate site to be considered acceptable; disqualifying conditions eliminate a candidate site from further consideration.

Just as the construction of the technical filter introduces considerable variation in strategies for selecting candidate sites for a deep geologic repository, so does the construction of the nontechnical filter. Arguably this filter's most important property relates to the power that a state or community can exercise. Since the early 1990s, nations outside the United States increasingly have constructed their nontechnical filters in ways that empower local jurisdictions. Many countries begin their site-selection process with a call for communities to volunteer.

The two filters are not independent of each other, except in some theoretical sense. The construction of the nontechnical one may affect the technical one in important ways. To begin with, applying the technical and nontechnical filters is neither purely mechanical nor can it typically be programmed neutrally. Further, implicit in a voluntarist approach is the presumption that a very wide range of geologic features and locations are suitable or can be made suitable. In some cases, this presumption is well-founded. In other cases, even after taking into account fairly general disqualifying conditions, potential disconnects may very well arise, so that applying *both* the technical and nontechnical filters yields a null set of potentially suitable and acceptable sites.

An additional source of variation among national programs can be traced to policies that govern the sequence for accepting or rejecting a candidate site. A country can adopt a "serial" policy whereby sites would be evaluated formally one by one until a suitable site was found. Alternatively, a "parallel" approach can be adopted in which at least two candidate sites would be characterized simultaneously and compared.

Site Selection for a Deep-Mined Geologic Repository

In all national programs, the implementer is responsible for proposing a site to develop as a deep-mined geologic repository. If only one site has been fully characterized at depth, as is the case in the French and American programs, it will be advanced by default if the implementer believes it to be suitable. In most countries, political ratification at the national level of any choice made by the implementer also must take place.

Approval to Construct a Deep-Mined Geologic Repository

The processes involved in obtaining approval to construct a deep-mined geologic repository are as varied as the processes involved in identifying candidate sites. In most countries, a representative body, such as the legislature or the Government, makes the final decision. Typically, that body relies on the regulators' advice. In some countries, however, the regulators make the final determination of whether the proposed repository system complies with established requirements.

Conclusion

In each of the 13 national programs considered in this report, the long-term management of HLW and SNF has proven more complicated and protracted than initially expected. What was formerly viewed as a relatively simple technical task is now recognized as a complex socio-technical problem involving political negotiations and institutional design challenges as well as path-breaking scientific and engineering analyses. Nonetheless, several national programs already have made considerable progress. Sites for a deep-mined geologic repository for HLW and SNF have been selected in four countries—Finland, France, Sweden, and the United States. License applications to construct such a facility have been submitted in two of those nations (the U.S. and Sweden). Applications are likely to be submitted in the other two within the next few years.

The information contained in this report suggests several important conclusions about processes used to develop a deep-mined geologic repository.

- *It is possible to elaborate a disposal concept and to advance a safety case, including quantitative performance assessments, that are widely credible not only to scientific and technical communities but also to broad segments of the general population and political leaders.* It appears as if a deep-mined geologic repository can be developed in a number of different hydrogeologic environments. An open and transparent technical assessment process, including international peer reviews, increases public and political support.

- *It is possible to find communities that are willing to host a deep-mined geologic repository.* From the experience gained in countries where sites have been selected, it appears that some communities do so because of their familiarity with other nuclear activities; others do so because of the economic benefits that might accrue in the future. All of those communities, however, were given a meaningful say in the site-selection process. And all of those communities came to be convinced by the respective implementers that the facility could be constructed and operated safely.
- *Although national programs differ in terms of what is considered an acceptable risk and how to demonstrate whether a deep-mined geologic repository satisfies those standards, international views on these matters are converging.* At least for the first few thousands of years after repository closure, dose constraints across countries are within a factor of three of each other and risk limits are within a factor of ten. Only for compliance periods on the order of 100,000 or 1,000,000 years has no international consensus yet been formed on dose constraints, risk limits, and methodology.
- *Organizational forms differ significantly across countries, but successful ones have several characteristics in common.* Nuclear industry-owned corporations have been successful in Sweden and Finland. A government agency has been successful in France. Rather than organizational form *per se,* what appears to be important are organizational behaviors, such as leadership continuity, funding stability, and the capacity to inspire public trust and confidence over long periods of time.

Today, more than a half-century after electricity was first produced by splitting the atom, the beneficiaries of that energy source have committed themselves to finding ways to manage the radioactive wastes thereby created in a technically defensible and socially acceptable way. That commitment should be a source for optimism, not only for the generation that produced the wastes, but for succeeding generations as well.

Introduction

The philosopher Hans Jonas has posed what may be the central ethical issue of our age when he tells his readers: "In your present choices, include the future wholeness of Man among the objects of your will" (Jonas 1973, 35-36). This modern-day injunction captures one aspect of the difficult decisions that are required for managing radioactive waste.

Since the early 1950s, more than three-dozen countries have generated electricity by harnessing the energy that holds together the nuclei of heavy elements, such as uranium and plutonium. Although the benefits of the energy produced to societies are substantial, the creation of different radioactive waste streams is an inevitable by-product of these efforts. This report focuses on the experience gained in 13 national programs for managing two of the streams: high-level radioactive waste (HLW) and spent nuclear fuel (SNF).[1]

Initially, the long-term management of HLW and SNF received relatively little attention from national policy-makers (OTA 1985).[2] HLW produced both as a consequence of a country's defense program and as a consequence of reprocessing a country's commercial SNF was stored at first as liquids in tanks. Although it is unclear how the material ultimately would have been managed, this option was considered a satisfactory final solution, especially for waste that had already been produced (AEC 1968 and U.S. Congress 1963).

Perpetual in-tank storage of liquid HLW, however, was soon seen as an unrealistic option. In 1955, the National Academy of Sciences' (NAS) Advisory Committee on Waste Disposal began a study intended to examine other options that might be more effective in isolating and containing HLW over the long-term. Although the writers of the study were careful to

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[1] In some countries, HLW and SNF also are produced as result of nuclear-weapons and nuclear-propulsion programs and as a result of experimental and research reactor programs. Typically, the requirements for the long-term disposition of those wastes are no different from the requirements for disposing of commercially generated waste. No further distinction will be made in this report among the various sources of high-activity radioactive waste.

[2] The discussion in this section focuses on the early days of radioactive waste management policy-making in the United States. A similar tale, however, could be told of the development of policies in the other countries that had generated radioactive waste by the end of the 1960s including the United Kingdom, France, and the Union of Soviet Socialist Republics.

note the need for further research, they stated categorically that they "… were convinced that radioactive waste could be disposed of safely in a variety of ways and in a number of sites in the United States." Further, they observed that "… disposal in salt is the most promising method for the near future …" (NAS 1957 3, 6). In retrospect, it appears that the NAS report instilled a sense of complacency in the minds of people dealing with radioactive waste management. The Academy's *imprimatur* left the impression that a "solution" could readily be found once it was needed. And, in fact, nearly a decade would pass before work started to implement the option of disposing of waste in a deep-mined geologic repository. Full development of such a facility to the operational stage has proven to be more problematic than many anticipated.

The difficulties of implementing a plan notwithstanding, the need for satisfactory options for managing HLW and SNF for the long term has not diminished. International and regional organizations, for instance, have highlighted the importance of developing approaches for the long-term management of HLW and SNF. Agreements, such as the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,* administered by the International Atomic Energy Agency (IAEA), and legislation, such as the draft directive proposed by the European Commission, call for the near-term adoption of policies and program to address this issue.

In the sections that follow, this report explores how 13 nations are carrying out efforts to find a permanent solution for isolating and containing HLW and SNF generated within their borders.[3] Many forces shape how those efforts are designed and implemented. Some of the forces are technical, including choices made about what reactor technology to adopt and about what nuclear fuel cycle to pursue. Others are social and political in nature, including how concerns about intergenerational equity should be addressed and at what pace the long-term management option should be implemented. Importantly, the interdependencies, both subtle and overt, among the technical, social, and political forces are inescapable. Because of those interactions, what characterizes the national programs most notably is their variety.

This report attempts to describe that variety. It builds on the information contained in the U.S. Nuclear Waste Technical Review Board's (NWTRB) *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel* (NWTRB 2009).[4] Unlike the earlier document, this report is more descriptive and considers the history of national programs.[5]

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[3] The countries are the United States, Belgium, Canada, China, Finland, France, Germany, Japan, the Republic of Korea, Spain, Sweden, Switzerland, and the United Kingdom. This report focuses entirely on the efforts of those countries to develop programs for the long-term management of HLW and SNF. It does not consider directly associated activities such as long-term storage, transportation of radioactive waste, and initiatives to reprocess SNF or recycle the reprocessed products.

[4] The reader is advised to refer to this Board report for more-detailed information about each national program.

[5] The discussion that follows includes illustrations drawn from various national programs. The illustrations were chosen to represent the *range* of approaches taken by the 13 countries; they are not meant to be exhaustive.

Process Considerations

All national programs keenly recognize today that the long-term management of radioactive waste is a complicated *socio-technical* problem, with the social dimension playing an integral role in determining the shape and the ultimate success or failure of a project (see, for example, IAEA 2007). National programs increasingly pay attention to issues such as public trust and confidence, transparency, stakeholder engagement, active participation in decision-making processes, and voluntarism.[6] Therefore, it is appropriate that this report begins with a discussion of the experience gained by national programs in devising processes, for it will be those processes that will come into play as countries either make key programmatic decisions in the future or debate whether to reexamine decisions made in the past. In the sections that follow this one, some of these key programmatic decisions are identified and discussed.

Engagement

Decisions in all countries about the long-term management of HLW and SNF were made initially by a small group of technical experts, industry representatives, legislative leaders, and government officials. When nuclear power and nuclear waste (and their connection) arose in the mid-1970s as issues for the broader public, the need to broaden opportunities for engagement became clear. In response, Belgium, Spain, the United States, Sweden, and Finland were among the first to pass legislation establishing frameworks in which radioactive waste management would be governed. Other countries followed suit. When they started to *implement* the new laws, however, national programs were forced to wrestle with thorny issues (NEA 2004b). Among these were: Should communities, the general

[6] At least one international organization, the Nuclear Energy Agency's (NEA) Forum on Stakeholder Confidence, was established solely to provide a venue to discuss these issues.

public, or representative non-governmental organizations be involved in the decision-making process? And if so, how should they be involved?[7]

Two patterns emerged as these questions were answered. First, traditional participatory mechanisms typically were mated with novel and more innovative ones. Second, especially as difficulties arose, many national programs came to recognize the importance the latter mechanisms and began to rely on them. For example, in the United States, participation frequently takes place under the umbrella of the Administrative Procedures Act and the National Environmental Policy Act. Agencies publish proposals and request public comment on them. Although the agencies are required to explain how they responded to all of the comments, they have broad discretion to accept or reject any of the input received. Yet, as with other nuclear facilities, a highly participatory adjudicatory process has to play out before a deep-mined geologic repository can be licensed. In Canada, the traditional mechanism of holding a public hearing on a proposed option for waste management failed to establish social acceptance for the approach (CEAA 1998). Subsequently, the Nuclear Waste Management Organization (NWMO) intensively and proactively engaged the public to secure acceptance of another waste management option (NWMO 2005).

ANDRA personnel explain the French repository design to members of the public. Source: ANDRA.

In Sweden during the 1970s and early 1980s, the Swedish Nuclear Fuel and Waste Management Company (SKB) used an approach to finding a suitable location for a repository that was similar to the one that had been used earlier to identify and propose sites for nuclear power plants. That proved unsuccessful, so starting in the 1990s, SKB encouraged communities to ask tough questions about what was being proposed (Sundqvist 2002). It also established a continuous presence in several communities and strongly supported a so-called “stretching” process in at least one of them.[8] National programs in Belgium and the United Kingdom envision the creation of partnerships between those responsible for

[7] Because all but one of the 13 countries are pluralistic democracies, these questions could not be easily dismissed or branded as illegitimate.

[8] Stretching involves the municipality developing and posing sharply focused questions to the body responsible for developing a deep-mined geologic repository and ensuring that the answers are responsive and specific.

implementing national programs for the long-term management of HLW and SNF and the communities that might be willing to host a deep-mined geologic repository (NEA 2010).[9]

It is worthy of note that the various engagement efforts conducted so far have altered the *technical approaches* adopted by national programs in some instances but not in others. For instance, in France, engagement with interested and affected publics highlighted the importance of designing a deep-mined geologic repository so that it would be reversible, thereby triggering a number of technical changes. In contrast, although the Swedish approach to disposing of HLW and SNF, KBS-3, has morphed over time, none of the technical changes were the result of input from communities that might serve as hosts for a deep-mined geologic repository. Instead, serious engagement seems to have served other functions, one of which is to increase public trust and confidence both in the local communities and at the national level.

Public trust and confidence

Attention has been drawn during the last twenty years to one factor, variously referred to as social or institutional trust, which appears to play an important, and perhaps even a decisive, role in determining the effectiveness, and perhaps the legitimacy, of public-engagement processes (Cvetkovich and Löfstadt 1999; IAEA 2007). Some national programs have come to merit considerable trust and confidence. In Sweden, for instance, the nuclear regulators enjoy broadly based social trust. Communities considering whether to host a deep-mined geologic repository express confidence in the regulators' judgments and are willing to base their decisions on those judgments (Ähagen et al. 2006). The national program in Finland has not had to confront a deficit of social trust. Other national programs, however, such as the one in the United States implemented by DOE, either have lost public trust and confidence or seem never to have merited it at all (Carter 1987; Herzlik and Mushkatel 1993). In France, a lack of social trust led to a moratorium on site-selection in 1990 (Barth 2009).

So critical is the development of social trust that several national programs have explored the issue specifically and, as indicated by reference to published reports below, have concluded that, absent widespread social trust, efforts to implement a long-term radioactive waste management approach are likely to confront significant, if not overwhelming, obstacles. In the United States, a Task Force advising the Secretary of Energy observed (SEAB 1993, 39):

> The legacy of distrust created by the Department's history and culture will continue for a long time to color public reaction to its radioactive waste management efforts. Only a sustained commitment by successive Secretaries of Energy can overcome it.

In Canada, a report by NWMO reached essentially the same conclusion (NWMO 2005, 75):

> Many examples have been brought forward of incidents in which the industry and/or government have acted in what is perceived to be a self-interested and secretive manner. For these participants, this is a key area in which trust must be built before proceeding with any approach for the long term management of used nuclear fuel.

[9] At the moment, the partnership in Belgium is addressing the management of low- and intermediate-level waste. The West Cumbria Partnership in the United Kingdom involves local governments interacting with the national government. The implementer is just observing the process.

Similarly in the United Kingdom, an advisory group appointed by Government, the Committee on Radioactive Waste Management (CoRWM), noted (CoRWM 2006, 14):

> There is also a high degree of historical distrust of the nuclear industry and those charged with developing waste management facilities, which has led to a breakdown of previous attempts to implement a policy.

In Canada and the United Kingdom, where waste-management programs are attempting to rebuild social trust, the initial signs seem positive. Sustaining trust appears to be a key consideration in decisions now being made. Research has shown, however, that recovering trust once it has been lost can be challenging (see, for example, Kasperson et al. 1992). Organizations that are not trusted have little "slack." What might have been forgiven were the agency considered trustworthy is often viewed as compelling evidence that the organization has not changed its ways fundamentally. Moreover, the context in which choices are made can make a difference. As a study by the IAEA recognizes, the situation changes once national programs go beyond their generic stages and confront the question of selecting candidate sites for a deep-mined geologic repository. Social trust, which might be established early on, may be harder to maintain as the programs mature or site-specific proposals are made (IAEA 2007).[10]

Decision-making strategies

In the last decade, attention has been drawn to what is presented as a new approach to making choices about the long-term management of HLW and SNF (NEA 2004a; NAS 2003; NWMO 2005). Often referred to as "adaptive management" or "staged decision-making," this approach is actually a refinement of the incremental decision strategy first detailed in the 1950s (Lindblom: 1959). Rather than decisive choices being made at the front end of the process, decisions are made in a stepwise fashion. At predetermined decision points, the work of national waste-management programs is reviewed and evaluated systematically by all interested and affected parties, and an explicit choice is made about whether to proceed along the program's proposed path or to reconsider what is to be done. A premium is placed on "organizational learning, flexibility, reversibility, auditability, transparency, integrity, and responsiveness" (NAS 2003, 124). National programs in Canada, France, Japan, Sweden, and Switzerland explicitly make this approach a centerpiece of their strategy for the long-term management of HLW and SNF. Other programs do not reject this approach but view it as nothing new, maintaining that they already have incorporated the strategy at least implicitly. [11]

At the theoretical level, it is hard to find fault with a decision-making strategy that seems to promise so much. As a more practical matter, however, it is still unclear whether it can be any more successful than earlier efforts in overcoming local and state opposition to specific siting decisions, whether it can be implemented, and even whether it *should* be implemented (Lee 1999). The many tensions between theory and practice are well

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[10] For a discussion of why it may be hard to implement recommendations to foster public trust and confidence, see SEAB: 1993, 61.

[11] It is unclear what Germany's position is. That country's *Safety Requirements Governing the Disposal of Heat-Generating Radioactive Waste* calls for "stepwise optimization." Yet only one license is likely to be issued by the regulators, covering authorization to construct a deep-mined geologic repository, to receive and possess waste, and to decommission the facility.

understood and often are acknowledged by the strategy's advocates, but two of them bear repeating here.

- In theory, supporters of a staged strategy contend that it fosters public acceptance by making national programs more responsive, even to the point of abandoning a project after substantial investments in it have been made. In practice, however, the approach detailed by Lindblom works best when there is *fundamental agreement* on outcomes at the start (Thompson and Tuden 1959).
- In theory, under a staged approach, those responsible for carrying out national waste-management programs openly acknowledge errors and uncertainties and make adjustments to correct mistakes. In practice, it is not unheard of that organizations cover up errors rather than acknowledge them. But even assuming a completely open-minded bureaucracy, discovering and rectifying mistakes is especially difficult when it comes to evaluating the performance of complex systems such as a deep-mined geologic repository (Vaughn 1996).

Perhaps the most important contribution that the proponents of such a structured and staged strategy have made is to identify a set of aspirations and objectives that national programs should strive to meet. It is by no means clear that a staged decision-making strategy is the only, or even the best, way to do so.

Remaining questions

Although there seems to be a general consensus about the importance of process considerations in the long-term management of HLW and SNF, questions remain about how to design processes that are effective given each nation's political culture. For example,

- Why will some communities volunteer to host a deep-mined geologic repository while others in the same country will not?
- Although adaptive staged management may be the most promising decision-making strategies for the long-term management of HLW and SNF, it is unclear how to design an approach that that can address issues such as possible disconnects between the need for mid-course corrections when evidence suggests that they may be required and the capability of institutions to make those changes.

There is no one recipe that can be chosen to ensure a successful process. Better understanding of processes, however, may lead to improved approaches (e.g., Chilvers and Burgess 2008; Cotton 2009) and adjustments also may be needed through time (e.g., Krutlia et al. 2010). Research on such issues has not been extensive, and much more knowledge is needed. The words of Jacob (1990, 164) remain true today: "While vast resources have been expended on developing complex and sophisticated technologies, the equally sophisticated political processes and institutions required to develop a credible and legitimate strategy for nuclear waste management have not yet been developed." More research also is needed on beliefs and perceptions and their linkage to behavior. For example, open questions remain about precautionary attitudes (e.g., Sjoberg 2009) and the connections among such factors as economic benefits, risk perception, and trust (e.g., Chung and Kim 2009).

Major summary points

- Two clear patterns describe how the participatory process has evolved in many nations. First, traditional mechanisms for public participation have been supplemented by novel and more innovative ones. Second, the more difficulty a program has encountered in the past, the more that national programs have come to recognize the importance of and to rely on active mechanisms for public engagement.
- Most existing siting processes now being implemented or contemplated by national waste-management programs involve some delegation of decision-making power to interested and affected outside parties.
- Although increased public involvement has affected key technical choices made by some national waste-management programs, it has had little effect on others.
- Some programs have undertaken significant actions to rebuild public trust and confidence, but, in many of those cases, the programs have not yet been put to the test; it remains to be seen how successful national programs will be in recovering lost trust.
- A staged decision-making strategy may offer the most promise for developing a deep-mined geologic repository, but it is unclear how well it can be implemented.

Development, Assessment, and Adoption of Waste-Management Options

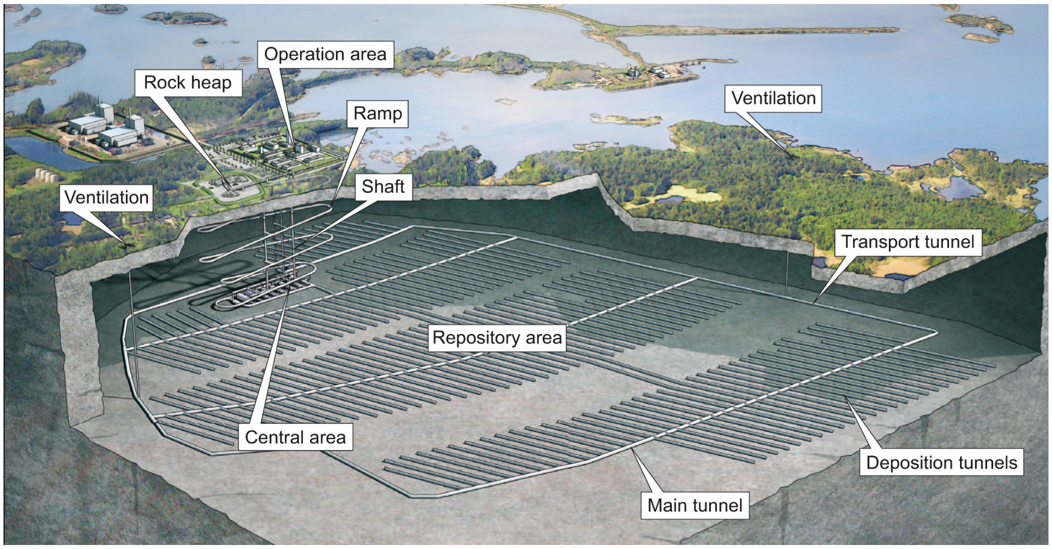
Over the years, national programs have explored a variety of options for the long-term management of HLW and SNF. These options have included the following (IRG 1978):

- Deep-mined geologic disposal
- Burying the waste in deep-sea sediments
- Placing the waste in deep-drilled boreholes
- Partitioning and transmuting the long-lived radioisotopes
- Shooting the waste into space
- Storing the waste indefinitely either above or below ground in a retrievable fashion.

Almost universally, policy-makers have determined that disposal of HLW and SNF in a deep-mined geologic repository is the preferred option for protecting human health and the environment for thousands of years.[12] As one international group put it, the option "… provides a unique level and duration of protection … It takes advantage of the capabilities of both the local geology and the engineered materials to fulfill specific safety functions in a complementary fashion, providing multiple and diverse barriers …" (NEA 2008b 7, 14).

In virtually all countries, the choice of disposal in a deep-mined geologic repository originally was reached implicitly by accepting a technical consensus that began to form more

[12] Neither Belgium nor Spain has officially adopted this option. The current Government in Scotland also is opposed to it, although previous Governments have supported the option of geologic disposal.



Conceptual view of the Swedish deep-mined geologic repository. Source: SKB

than 50 years ago with the publication of the NAS report.

In some countries, that choice was never formally reconsidered.[13] For example, by 1977, the first so-called KBS report suggested that vitrified HLW should be placed in a deep-mined geologic repository. That report, however, also outlined the possibility of depositing SNF in such a facility. As Sweden gradually shifted to a strategy of direct disposal of SNF, SKB developed two conceptual plans culminating in the adoption of KBS-3 (SKB 1978a, 1978b, 1983). During that period, some details were finalized: The copper option was chosen for the waste package instead of ceramic; vertical emplacement of the waste packages was picked over horizontal emplacement; and bentonite rather than a mixture of bentonite and quartz sand was selected as the buffer. But one element of the conceptual plans has remained constant: A deep-mined geologic repository would be developed in the crystalline rock that is so prevalent in Sweden.

The Germans began in 1965 to construct an underground laboratory at Asse in Lower Saxony to determine whether salt might be a suitable host formation for disposing of HLW. By the early-1970s, the federal government selected that rock type. In 1973, a siting process was launched for the Integrated Waste Management Center, where a repository for HLW and long-lived intermediate-level waste would be co-located with a reprocessing facility. A site close to the community of Gorleben, also in Lower Saxony, was chosen four years later (Hocke and Renn 2010).[14]

In the United States between 1965 and 1967, researchers from Oak Ridge National Laboratory carried out studies at the inactive Carey Salt Mine outside of Lyons, Kansas. Their work helped confirm the optimism expressed in the NAS report about the suitability of salt as a host rock. The Atomic Energy Commission (AEC) in 1970 officially selected disposal in a deep-mined geologic repository as the sole option for the long-term management of HLW (AEC 1970). Disposal in a deep-mined geologic repository was more firmly established in law with the passage of the Nuclear Waste Policy Act (NWPA) in 1982.

National waste-management programs in Canada and France also initially chose the geologic disposal option but were compelled by public pressure to reconsider other options explicitly. In 1978, the Governments of Canada and Ontario announced the creation of a

[13] The passage of environmental impact legislation has affected how waste-management options are chosen. Although the option of disposal in a deep-mined geologic repository was, for all practical purposes, selected in the United States in 1970, it was not until 1980 that the environmental assessments necessary to support that choice were completed (DOE 1980).

[14] In Germany, perhaps more than any other country, the fate of national program for managing HLW and SNF is closely tied to the ongoing debate over the future of nuclear power.

program to dispose of radioactive wastes from nuclear power reactors in a deep-mined geologic repository developed in intrusive igneous rock. To establish the technical basis for this program, the Whiteshell underground laboratory was built near the town of Pinawa in Manitoba, and experiments were conducted there for more than a decade.

In 1994, Atomic Energy of Canada Limited (AECL) submitted a comprehensive Environmental Impact Statement based on the concept of placing SNF in corrosion-resistant copper containers at a depth of between 500 and 1,000 meters in plutonic rock located in the Canadian Shield (AECL 1994). After extensive public hearings, the Government-appointed Seaborn Panel issued its findings evaluating the concept (CEAA 1998).

- Broad public support is necessary in Canada to ensure the acceptability of a concept for managing nuclear fuel wastes.
- Safety is a key part, but only one part, of acceptability. Safety must be viewed from two complementary perspectives: technical and social.
- From a technical perspective, the safety of the AECL concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it has not.
- As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support. The concept in its current form does not have the required level of acceptability to be adopted as Canada's approach for managing nuclear fuel wastes.

When the Canadian Government subsequently accepted the findings and recommendations of the Seaborn Panel, in effect it threw out the waste-management option that had been the basis of Canada's waste-management program for 20 years.

Starting from scratch NWMO reviewed more than a dozen waste-management options and decided to analyze three of them in-depth:

- Deep geologic disposal in the Canadian Shield
- Storage at nuclear reactor sites
- Centralized storage above or below ground.

In the end, NWMO recommended to Government a fourth option, what it termed "a technical method and a management system" (NWMO 2005). This option had the following features:

- Ultimate centralized containment and isolation of used nuclear fuel in an appropriate geologic formation
- Phased and adaptive decision-making
- Optional shallow storage at the central storage site prior to placement in the repository
- Continuous monitoring
- Provision for retrievability
- Citizen engagement.

In 2007, Government adopted NWMO's recommendations and accepted the Adaptive Phased Management approach as the best option for the long-term management of nuclear-fuel waste.

The French waste-management program underwent a similar crisis in public confidence and also was forced to re-examine its choice of waste-management options. By the mid-1980s, the Government had identified four specific sites—in clay, crystalline rock, schist, and salt—where a repository might be developed. Some test boreholes were drilled, and analyses were undertaken to determine how to optimize the waste isolation system, "… taking into account the overall characteristics of the particular host rock" (Carter 1987, 323). The four sites were selected based on technical judgments on their merit, and their selection did not involve much participation either by the public at large or by the local authorities. Subsequently, intense local opposition emerged at all four sites, and the Prime Minister called a halt to the site-selection process in February 1990.

Parliament passed new legislation governing radioactive waste in December 1991. The Research in Radioactive Waste Management Act reopened the question of what waste-management option should be adopted. It laid out in clear terms major areas of research, which were to be carried out by the National Radioactive Waste Management Agency (ANDRA). They were:[15]

- Partition and transmutation
- Waste packaging and effects of long-term surface storage
- The feasibility of reversible and non-reversible deep-mined geologic disposal through studies conducted in underground research laboratories.

The Parliamentary Office for the Evaluation of Science and Technology Options (OPECST) held three days of public hearings on radioactive waste management in early 2005. The hearings covered partitioning and transmutation, deep-mined geologic disposal, and long-term interim storage. The hearings were conducted to inform a report that was prepared by OPECST and released later that year (OPECST 2005).

Following the national public debate, and taking it into account, the Sustainable Management of Radioactive Materials and Waste Act was submitted to and passed by Parliament in 2006. The Act selected phased deep geologic disposal as the preferred option for managing HLW and dictated that a deep-mined geologic repository be developed at a site to be chosen by 2015. However, in anticipation of the deployment of fast reactors, the research then under way into partitioning and transmutation of long-lived radioactive elements would be continued.

The situation in the United Kingdom is a bit different and more complicated. That country envisioned reprocessing all of its SNF. Just as in the United States, some thought was given to storing the liquid HLW in tanks for an indefinite period. That waste-management option, however, was abandoned in 1976 when a Royal Commission on Environmental Pollution severely criticized it. By then, Government concluded that developing a repository for vitrified HLW was too onerous and decided to concentrate on managing the long-lived intermediate-level waste from reprocessing. Over the next few years, attempts were made to obtain from local communities "planning permission" to drill surface boreholes

[15] An amendment to the Act was passed in early 1998 to allow funding for a fourth major research area, the evaluation of interim storage options.

to determine whether sites selected by the Institute of Geological Sciences might be suitable for developing a deep-mined geologic repository. Planning permission was granted at one of the sites, and a Public Inquiry was launched at another one. By 1981, Government had come to view developing a deep-mined geologic repository as politically infeasible and had concluded that long-term surface storage of solidified HLW, not disposal, should become the nation's preferred waste-management option.

Not until the late 1980s did the United Kingdom venture back into the realm of geologic disposal of HLW and SNF. Industry-owned UK Nirex Limited applied for planning permission to construct a Rock Characterization Facility near the reprocessing site at Sellafield in West Cumbria. The facility would have permitted characterization of the rocks to determine whether they are suitable for a deep-mined geologic repository for long-lived intermediate-level waste. After a Public Inquiry at which strong opposition to the facility was voiced, the local government refused planning permission. This decision was confirmed at the national level in 1997.

Unlike the similar situation two decades previously, Government realized that it could not avoid addressing the question of long-term management of HLW and SNF. To do so, it launched the Managing Radioactive Waste Safely consultation program in 2001. As part of the program, CoRWM was asked in 2003 to make recommendations on what options the country should adopt.

CoRWM began its evaluation by identifying waste management options that had been suggested in the past. The list included the following:

- Interim or indefinite storage on or below the surface
- Near-surface disposal, a few meters or tens of meters below ground
- Deep disposal, with the surrounding geology providing a further barrier
- Phased deep disposal, with storage and monitoring for a period
- Direct injection of liquid wastes into rock strata
- Disposal at sea
- Subseabed disposal
- Disposal in ice sheets
- Disposal in subduction zones
- Disposal in space, into high orbit, or propelled into the Sun
- Dilution and dispersal of radioactivity in the environment
- Partitioning of wastes and transmutation of radionuclides
- Burning of plutonium and uranium in reactors

CoRWM then developed a set of screening criteria to narrow the list. It used two rounds of public-engagement meetings to inform its assessment of the options. The shortlist for detailed evaluation contained only three options, which, in CoRWM's view, could be implemented in principle to manage the country's entire inventory of HLW and SNF: interim storage, geological disposal, and phased geological disposal. In 2006, CoRWM made its recommendations (CoRWM 2006). Several months later, Government responded by accepting geological disposal coupled with safe and secure interim storage as the way forward for the long-term management of the United Kingdom's higher activity wastes and designated the Nuclear Decommissioning Authority (NDA) as the responsible organization (UKG 2006).

Although 11 out of the 13 nations considered in this report are officially committed to developing deep-mined geologic repositories as the preferred option for the long-term

Table 1

STATUS OF THE REPOSITORY-DEVELOPMENT PROGRAMS FOR HLW AND SNF

COUNTRY	STATUS
United States	License application for a repository at Yucca Mountain in Nevada was submitted to the Nuclear Regulatory Commission (NRC) in June, 2008. Subsequently, the Administration sought to withdraw the application and to defund the project. No final decisions have been made.
Belgium	Geologic disposal has not been officially adopted as the country's preferred long-term waste management option, although investigations have been conducted in clay. Start of repository operations is anticipated in the 2040 time frame.
Canada	Engagement with the public determined the criteria that will be used to select candidate sites for a repository. Eight communities in two Provinces have expressed an interest in learning more about the possibility for hosting a repository. No date has been for the start of repository operations.
China	Preliminary site investigations are under way at Beishan in the Gobi Desert. Start of repository operations is anticipated in the 2050 time frame.
Finland	A site at Olkiluoto near the community of Eurajoki has been selected for a repository. Site investigations and construction are under way. Start of repository operations is anticipated in the 2020 time frame.
France	A site in the Meuse/Haute-Marne region has been selected for a repository. Site investigations are underway. Authorization to construct the repository is anticipated in 2017. Start of repository operations is anticipated in the 2025 time frame.
Germany	After a hiatus of 10 years, Government has announced that site investigations at Gorleben would resume. No date for the start of repository operations has been set.
Japan	Generic investigations have been conducted in crystalline rock. In 2002, the Government sought volunteer communities to explore the feasibility of constructing a final repository for HLW. To date, no community has agreed to volunteer. No date has been set for the start of repository operations.
Republic of Korea	The repository development process for HLW and SNF has not begun.
Spain	Geologic disposal has not been officially adopted as the country's preferred option for long-term waste-management.
Sweden	A site in the municipality of Östhammar has been selected based on site investigations. A license application to construct a repository was submitted in March 2011. Start of repository operations is anticipated in the 2023 time frame.
Switzerland	The first of three phases of the site-selection process has begun. Start of repository operations is anticipated no sooner than 2040.
United Kingdom	Two communities in West Cumbria are discussing with Government the possibility of participating formally in the site-selection process for a repository. Start of repository operations is anticipated in the 2040 time frame.

management of their HLW and SNF, the pace of the development process varies considerably. For some national waste-management programs, moving forward expeditiously is the best way to address concerns about intergenerational equity. Those countries typically have made firm decisions about whether to reprocess their SNF. Nations projecting a longer time horizon believe that many of their citizens still have not accepted that deep-mined geologic repositories are an appropriate strategy for permanent disposal of HLW and SNF and that they therefore must plan for an extended period prior to development of a repository during which technical work and public engagement will continue (Table 1).

Major summary points

- A broad consensus has emerged over the last 50 years that properly sited and designed deep-mined geologic repositories can isolate and contain HLW and SNF for many thousands of years, thereby adequately protecting human health and the environment.
- Countries whose waste-management programs have been challenged and disrupted have subsequently conducted an explicit and transparent evaluation of options to inform a national decision on whether to adopt disposal in deep-mined geologic repositories as the preferred approach. In all cases, that option was selected.
- The pace at which national repositories are being developed varies considerably. Factors affecting the development schedule include public and political acceptance, attitudes toward nuclear power, views on intergenerational equity, and a desire not to foreclose the possibility of extracting additional energy from SNF.

Institutional Arrangements for Executing Waste-Management Programs

Every national waste-management program must address two interrelated questions: Which organizations should be assigned the responsibility for executing which parts of the program, and how will the program be funded? The 13 countries have answered those questions in strikingly different ways.[16]

Organizations

At least two institutions are involved in executing national waste-management programs: the implementer and the regulator. The implementer is responsible for developing a safety case, identifying and characterizing candidate sites, and designing, building, and operating the deep-mined geologic repository. The current organizational form of the implementer varies considerably across the countries.

Some nations have opted to use a traditional government agency. In the United States, at the same time that geologic disposal was selected as the preferred waste-management option, the AEC also deliberated over what type of organization should develop and operate a deep-mined geologic repository. Only the tiny Division of Industrial

[16] The Detailed Tables in NWTRB 2009 provide additional information about the organizations that are part of each national waste-management program.

Participation voiced any objections to the decision that the responsibilities should belong to the federal government.[17] In Germany and the Republic of Korea as well, the implementer of the waste-management program is a government agency.[18] France considers its implementer to be a government-owned public service agency. In the United Kingdom, the NDA, a non-departmental public body under the purview of the Department of Energy and Climate Change, is the implementer.

In other countries, the implementer is a private corporation. Beginning in 1973, SKB, jointly owned by the nuclear power producers, took charge of efforts to develop an approach for disposing of, at first, HLW, and now, SNF.[19] In Canada and in Finland, the implementers, NWMO and Posiva Oy respectively, are organized and tasked in much the same way.[20] In still other countries, the implementers are hybrid organizations. Government-owned corporations are the implementers in Belgium, China, and Spain. In two nations, the implementing organization takes on idiosyncratic forms, combining in varying degrees public and private characteristics. In Japan, a private non-profit corporation, the Nuclear Waste Management Organization (NUMO), was established by the owners of nuclear power plants and is supervised by the Ministry of Economy, Trade, and Industry. In Switzerland, a private/public consortium of radioactive waste producers, the National Cooperative for the Disposal of Radioactive Waste (NAGRA), includes the owners of nuclear power plants and the Federal State.

The organizational form of the implementer in seven of the 13 the national programs examined in this report has remained the same (Belgium, Finland, France, Germany, Sweden, Switzerland, and the United States). In France, for example, the Atomic Energy Commission (CEA) was responsible for the first research undertaken to develop a deep-mined geologic repository. Because of concerns about waste management efforts being overwhelmed within the large CEA, ANDRA was established in 1979 as a separate unit within the CEA. As will be discussed below, ANDRA encountered difficulties when it tried to initiate site investigations. That experience led in 1991 to Parliament's passage of the Research in Radioactive Waste Management Act, one provision of which called for ANDRA to be removed from the CEA and made into a government-owned public service agency.

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[17] The Division of Industrial Participation was a unit within the AEC, charged with expanding commercial opportunities for the private sector. Its limited influence made it no match for the Reactor Development Division, which championed the option of having a government agency be responsible for developing a deep-mined geologic repository.

[18] In Germany, the 4th Amendment to the Atomic Energy Act of 1976, which assigned the task of waste disposal to the Federal Government, stipulated that the Government could make use of third parties to discharge those duties. Toward this end, the Government created the German Service Company for the Construction and Operation of Waste Repositories (DBE) and entered into an exclusive contract with it. DBE is currently 25 percent state-owned with the balance owned by German nuclear utilities, although state ownership will double shortly. In Korea, the Radioactive Waste Management Company was created by Parliament in 2008. It has been described as an "umbrella organization set up to resolve South Korea's waste management issues and waste disposition, and particularly to forge a national consensus on high-level wastes" (WANO 2010). No further information is available about this implementer's organizational form. Until it has been established and begins operations, responsibilities for waste management are vested in a government agency.

[19] When SKB was formed in 1973, the Swedish State, through its ownership of utilities, was the major nuclear-electricity generator at the time. SKB initially focused on the supply of fuel to the nuclear power plants. By the mid-1970s, the company's focus had shifted to nuclear waste management.

[20] Some of the Canadian, Finnish, and Swedish utilities that own the implementers are partly government-owned.

In Canada, Japan, and the United Kingdom, government agencies were the initial implementers, perhaps the result of a legacy dating from the time when nuclear energy policy was deemed so exceptional that it had to remain under tight government control. Significant shifts over time, however, have taken place, typically away from government and towards hybrid or private organizational forms. These changes appear to have a common root cause, namely, a response to major programmatic challenges.

AECL was established in 1950 as a federal Crown corporation with the responsibility for managing Canada's nuclear energy program (including radioactive waste management), conducting research and development, and carrying out a number of commercial operations, such as the promotion of the CANDU reactor. The rejection of AECL's conceptual disposal plan in 1998 led Government to revise the structure of its waste-management program. The subsequent passage of the Nuclear Fuel Waste Act in 2002 transferred responsibility to NWMO, which is jointly owned by the three nuclear utilities that have generated SNF.

The Japanese Government first placed efforts to develop a deep-mined geologic repository in the hands of the country's Atomic Energy Commission. But the waste-management program developed slowly. Concerned that the absence of a repository could impede the construction of additional nuclear power plants, Parliament passed the Final Disposal of Specific Radioactive Wastes Act in 2000, which established NUMO.

In the United Kingdom, responsibility for developing a deep-mined geologic repository was initially given to the Atomic Energy Authority (UKAEA). Its inability to get planning permission from a number of communities to characterize sites in the mid-to-late 1970s led to the creation of the Nuclear Industry Radioactive Waste Executive and then to UK Nirex. As noted previously, the failed attempt in the late 1990s to obtain planning permission for the Sellafield Rock Characterization Facility forced Government to reconsider its waste-management efforts, culminating in the adoption of the Managing Radioactive Waste Safely program. In 2005, ownership of UK Nirex was transferred from the nuclear industry to the government of the United Kingdom and, in 2007, UK Nirex was disbanded and its staff transferred to the NDA. Within the NDA, the Radioactive Waste Management Directorate has primary responsibility for developing a deep-mined geologic repository. Its conversion into a "site licensing company" is under way.

Both the variety and the evolutions of the implementers' organizational form seem to demand an inquiry into the question: Which form is best? A simple analysis that tries to associate particular forms with the completion of repository-development milestones produces no clear-cut conclusions: Of the four national programs furthest along, one has been implemented by a government agency (United States), one by a government-owned public service agency (France), and two by private corporations (Finland and Sweden).

In 1982, when Congress passed the NWPA, it also commissioned a study to identify an appropriate organizational form for the American implementer. The Advisory Panel on Alternative Means for Financing and Managing Radioactive Waste Facilities, among other things, evaluated four arrangements (AM FM: 1984). It ended up endorsing a FEDCORP, that is, a government-owned corporation structured to operate more like a private enterprise than a government agency. The panelists reached that conclusion based on the weights they gave to the lengthy lists of pros and cons associated with each arrangement. Both DOE and the U.S. nuclear industry, using their own weights, held that the *status quo* should be maintained (see, for example, Harrington 1985).[21] In 2001, Congress asked the DOE to follow up on the earlier evaluation. DOE evaluated three arrangements and developed a lengthy list of pros and cons associated with each arrangement. Ultimately, DOE was not prepared to choose among the alternatives and concluded that they should be studied further once a decision on the Yucca Mountain site had been made (DOE 2001).

Combining the experience gained by 13 national programs with the more detailed analyses undertaken in connection with the U.S. program suggests that the answer to the question posed above is that it depends. Some interested and affected parties will care strongly that the implementer is responsive to their views; others will want the implementer to focus on meeting schedules or minimizing expenditures. Each country seems to find its own particular way to resolve these value-based conflicts. In the final analysis, what may be most critical is not organizational form *per se* but organizational behaviors.

In all 13 national waste-management programs, the regulator is a government organization. The regulator determines whether the approach advanced by the implementer is acceptable. Very early on in some countries such as the United States, the implementer and the regulator were the same organization. Now there is general agreement that the two institutions should be independent of each other, even if, as in Germany and Japan, they are housed within the same government bureaucracy (see, for example, NEA 2009). In some countries, such as the United Kingdom and the United States, multiple regulators have authority over the development of deep-mined geologic repositories.

In six of the 13 nations, independent oversight organizations have been created. Some of them, including the NWTRB, the National Review Board in France (CNE), the Nuclear Waste Management Commission in Germany, and the Nuclear Safety Commission in Switzerland, limit their oversight to technical matters. Others, including the National Council for Nuclear Waste in Sweden and the reconstituted CoRWM in the United Kingdom, have a broader mandate and provide oversight on non-technical matters as well as technical ones. All of these oversight organizations reach conclusions about how well the implementer is carrying out its responsibilities and make recommendations for improvement to some government body or bodies. Typically, they lack the power to enforce their recommendations, although in some countries the presumption is that their advice will be accepted (see, for example, U.S. Congress 1987).

Finances

Developing and operating a deep-mined geologic repository is a decades-long undertaking. That period can stretch out even further if a nation decides to close the facility only after an extended monitoring program. Ensuring adequate funding for such a lengthy program can present substantial challenges. Credible cost estimates have to be calculated and then periodically updated as new information emerges. Mechanisms have to be put into place to

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[21] The AM-FM study, which is the most systematic one to date, still advances impressionistic claims that are only tenuously based on evidence. See Thomas 1993.

collect the needed revenue, to make certain that it is spent only for its intended purpose, and to undertake long-term planning to develop a deep-mined geologic repository.[22]

Two main approaches toward financing have been adopted by the 13 countries examined in this report. First, special funds have been set up in Canada, Finland, France, Spain, Sweden, Switzerland, and the United States to which waste producers or the consumers of nuclear-generated electricity contribute each year. Second, the expenses incurred by waste-management programs in China, Germany, and the United Kingdom are paid annually out of general government revenues. Although special funds have been established in Belgium, Japan, and the Republic of Korea, the expenses of their current waste-management programs are not covered by the funds but by general government revenues.[23]

Although the total system life-cycle costs of developing, operating, and decommissioning a deep-mined geologic repository are estimated by a government agency in all countries but Finland and France, national waste-management programs that have established special funds have done so in different ways. In Canada, NWMO proposed a rather complex formula for determining the annual contributions from the three nuclear utilities and AECL (NWMO 2007). Government approved the formula in 2009. Each contributor deposits its payments in separate, segregated trust funds. Approximately $60 million (Canadian) is collected annually. Each year in Finland, generators pay the difference between the estimated fund target liability incurred to date and the amount that they had previously paid (Finnish Energy Industries 2007). Payments can be in securities. Excess payments can be recovered. The fund is controlled and administered by the Ministry of Trade and Industry.

Nuclear waste generators in France establish reserves to cover the full costs of long-term management of their wastes (ANDRA 2009). These reserves are held separately within each company. Every three years, each generator transmits to an independent government commission a report describing how the costs were estimated and the choices adopted for the composition and management of the reserves. The commission, composed of parliamentarians and individuals appointed by Parliament and the Government, has the authority to require additional contributions if it concludes that a generator's payments are insufficient. In Sweden, the holders of a license to operate a facility that generates radioactive waste must pay a fee to the State. The fee, which is now set by Government every third year, is calculated on a per-kilowatt-hour basis. Owners of facilities that no longer operate must pay special fees for the uncovered costs of managing their SNF. If the fund is insufficient, the generators must provide a guarantee to make up any deficit (Kärnavfallsfonden 2010). The accumulated funds are managed by a government authority. In Switzerland, approximately 35 percent of the anticipated total system life-cycle costs already has been paid for and spent. Another 17 percent is the costs to be incurred by the generators between 2008 and the time that their facilities are decommissioned. The remaining 48 percent will be covered by contributions to the fund (SFOE 2009).

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[22] In France and the United States, the total cost is divided between the generators/consumers of nuclear electricity and the government, which has to pay to manage waste from defense nuclear programs. In the United Kingdom, the government will pay the costs of disposing of waste from defense nuclear programs and waste from the older operating and decommissioned nuclear power plants. The costs of managing waste from new-build nuclear power plants must be paid by their owners.

[23] In Germany and Belgium, the waste producers reimburse the government.

In the United States, DOE is required to prepare an annual estimate of the total system life-cycle costs of developing, operating, and closing a deep-mined geologic repository for SNF and HLW. Based on that estimate, it has to recommend to Congress whether the legislatively dictated fee of 1 mil/kilowatt-hour[24] of nuclear-generated electricity that utilities contribute to the Nuclear Waste Fund (NWF) should be revised. Although called a trust fund, the monies held in the NWF as a practical matter are not segregated. Thus they effectively pay for other government programs. Moreover, because Congress appropriates money to develop a repository strictly on an annual basis, DOE has to cope with widely varying budgets and often does not have direct access to the funds that have accumulated.

Major summary points

- Implementers of waste-management programs take on a variety of institutional forms. In general, there does not seem to be any connection between institutional form and "progress" toward constructing and operating a deep-mined geologic repository.
- The choice of organizational form for the implementer depends in each country on how value-based conflicts are resolved. There does not seem to be "one best way" that can be universally applied.
- The costs of some national programs are paid from general government revenues. Other national programs have devised formulas and procedures for determining how much money should be collected from waste generators based on estimates of the total system life-cycle cost. In most countries, those funds are deposited into segregated accounts.

[24] One mil equals $0.001.

Technical Basis for Developing Disposal Concepts and Supporting a Safety Case

In all countries, the implementer has the responsibility for developing a disposal concept that describes a repository system comprising natural and engineered barriers. In most countries, limitations imposed by the geology constrain which disposal concepts can be considered. The implementer typically ends up focusing on one particular geologic formation because of its prevalence or because other formations either are unsuitable technically or cannot be developed because of land-use conflicts. Once a host rock has been chosen, the implementer considers the hydrogeologic environment and determines what, if any, engineered barriers are appropriate as well as how the repository system as a whole will be designed.[25] The implementer then is expected to advance its safety case, a set of arguments and analyses demonstrating why the proposed deep-minded geologic repository will isolate and contain HLW and SNF for as long as society demands.[26] (Various standards and regulatory requirements reflect those demands.) There is broad scientific agreement that deep-mined geologic repositories can be constructed in a wide variety of host-rock formations and hydrogeologic environments, including in salt, crystalline rock such as granite, different clay formations, and unsaturated volcanic tuff.[27] A brief discussion of the work to evaluate each host-rock type for permanent disposal of HLW and SNF follows.

[25] A more technically defensible approach would be to focus on the total hydrogeologic environment rather than rock type.

[26] The viability of any disposal concept ultimately will depend on finding an appropriate site and characterizing the site in sufficient detail.

[27] An excellent resource for understanding the development of disposal concepts is NEA 2008a.

Salt

Disposal of HLW and SNF in salt has been explored in detail in several countries for more than a one-half of a century. When the NAS first proposed developing such a repository, it noted that "… the great advantage is that no water can pass through salt. Fractures are self-sealing …" (NAS: 1957, 4-5; Appendix F). Those two properties have been at the core of the salt disposal concept adopted, for example, by the German waste-management program.[28]

Disposal concept

As originally articulated, the salt disposal concept appears to be extremely elegant in its simplicity. Put in the simplest terms, if the salt is there, water flow, the predominant mechanism for transporting radionuclides to the biosphere, is not occurring at rates of concern for waste disposal. It is then just a matter of carving out drifts in the formation. Waste is lowered and emplaced into the drifts, most likely in boreholes. The shafts leading to the repository, the drifts themselves, and the boreholes then are sealed with crushed and compacted salt.

Under lithostatic pressure exerted by the layers of rock above the repository, the salt flows slowly, closing around emplaced disposal packages and healing any fractures or voids that may have formed during the construction phase. Waste packages are not considered long-term barriers for isolating and containing HLW and SNF because localized brine inclusions could cause them to fail. Even so, because the environment in the repository would evolve over several hundred years from being oxidizing to become reducing, the waste would remain in a relatively insoluble form.

It is possible to analyze disposal of HLW and SNF in salt generically to determine whether it is an appropriate host rock for a deep-mined geologic repository. Those generic studies would have to address questions about the effects of heat on brine migration and whether pressures become too great when hydrogen is generated as small amounts of water contact the waste. Moreover, extensive underground exploration of salt beds or domes would be required to determine whether a particular site might be suitable for a deep-mined geologic repository. But at least some participants in the German program believe that an undisturbed deep-mined geologic repository in salt will have zero release of radionuclides to the biosphere for at least one million years (Krone et al. 2008).[29]

Safety case

The safety case for disposing of HLW and SNF in salt involves a demonstration that the undisturbed geologic barrier would perform as anticipated and that engineered barriers (mainly shaft, drift, and borehole seals) would prevent brine inflow through the man-made penetrations of the salt barrier, thereby ensuring that any movement of dissolved radionuclides along those pathways will be minimal.

Sophisticated modeling work has been carried out to support the proposition that a disturbed salt repository holding non-heat-generating waste will isolate and contain radioactive waste for long periods of time (EPA 2006). Additional modeling appears to

[28] A very similar concept was used by DOE in developing the disposal concept for defense-origin transuranic waste at the Waste Isolation Pilot Plant (WIPP) in New Mexico.

[29] This position is consistent with the safety analysis carried out at WIPP in that the hypothetical releases are dominated by the human intrusion scenario. "Natural" releases are calculated to be minuscule (Westinghouse 1995).

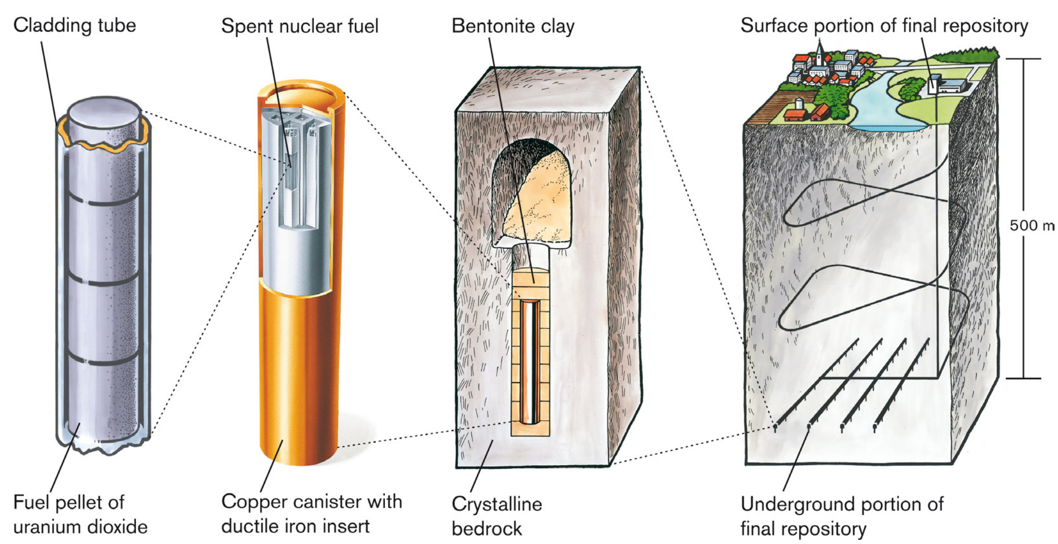
support the proposition for heat-generating waste as well, although that claim has not been subjected to a formal empirical or regulatory test. Toward that end, experiments have been conducted to understand the compaction behavior of crushed salt. Investigations have been carried out to thermally simulate disposal in drifts of waste packages containing SNF. Based on these studies, experts from the German program argue that the engineered elements of the repository it contemplates using (other than the waste packages) would function reliably (Müller-Hoeppe et al. 2008). So far however, no country has advanced a comprehensive safety case for disposing of HLW and SNF in salt.

Crystalline rock

The KBS-3 plan developed by the Swedish program, supplemented by work carried out by the Canadian and Finnish programs, has resulted in a well-articulated crystalline rock disposal concept. The viability of this disposal concept depends on finding a site where the acidity and the oxidation-reduction potential of the groundwater enveloping the crystalline rock formation fall into an appropriate range. In that case, according to the laws of thermodynamics, elemental copper would not react with the groundwater and thus waste packages made of that material would contain the SNF virtually forever. Sites that have few fractures add an extra layer of protection.

Disposal concept

KBS-3 envisions a repository system composed of multiple compatible natural and engineered barriers. Groundwater in Swedish crystalline basement rock possesses the requisite chemical and electrochemical properties. The crystalline rock, however, is not impenetrable. Fractures permit groundwater to flow within the typical formation, although the flow usually is quite slow, thereby limiting release of radionuclides to the environment.



The KBS-3 method of disposing spent nuclear fuel. Source: SKB.

To reduce further the release of radionuclides, engineered barriers are critical elements of the KBS-3 plan. Rings of bentonite clay are used to line the boreholes where the packages will be emplaced. This material further limits exposure of the copper canisters that contain the SNF to the groundwater. The bentonite also protects the canisters in the event of small movements in the rock and delays the spread of radionuclides that might escape from the waste package. The repository is designed so that the drifts can be backfilled with bentonite. The waste package features a canister, which is constructed from five-centimeter thick copper. In addition to being corrosion-resistant in the repository's environment, the canister can withstand some of the mechanical forces caused by the movement of the rock (Hedin 2008). Inside the copper canister is a nodular cast-iron insert to increase the mechanical strength of the waste package.

Safety case

The safety case for the crystalline rock disposal concept depends most importantly on groundwater having favorable chemical properties, including acidity, oxidation-reduction potential, and dissolved solutes. All alternative corrosion mechanisms to the one articulated in the disposal concept have to be investigated to ensure that copper will remain in its elemental state. Bentonite has to be shown to limit advective transport under the chemical, thermal, mechanical, and hydrologic conditions expected to be present in the deep-mined geologic repository. Techniques for flawlessly welding lids on to the waste package must be demonstrated.

SKB has studied these issues. It has constructed laboratories to test the properties of bentonite under a wide range of conditions. It also has built a laboratory to investigate methods for welding and inspecting canister lids at an industrial scale. It has undertaken preliminary work to investigate the claim that new mechanisms have been identified by which copper might corrode in the basement rock. An extensive review of this particular issue, however, by the oversight body largely concluded that the claim was not technically supported (Swedish National Council for Nuclear Waste 2009). A report, however, to the Swedish Radiation Safety Authority (SSM) suggests that this controversy has not yet been put entirely to rest (Macdonald and Sharifi-Asi 2011).

The KBS-3 plan has been subjected to rigorous national and international peer-review (see, for example, NEA 2001). SSM and the National Council for Nuclear Waste have regularly evaluated SKB's plans to address outstanding technical issues. Neither organization has found flaws with the disposal concept that would require its abandonment or radical revision (see, for example, Swedish National Council for Nuclear Waste 2008). Confidence in the concept is increased because intact copper nodules, millions of years old, have been found enclosed in the same type of formations that might someday host a deep-mined geologic repository.

All information obtained through its research program was analyzed by SKB as it prepared a license application, which was submitted to the authorities in March 2011. As part of that application, SKB carried out a quantitative postclosure safety analysis of the proposed facility, primarily by estimating the possible dispersion of radionuclides and how those releases would be distributed in time for a representative selection of future potential scenario sequences.

Clay

A repository mined out of a layer of clay or clay-like materials may be an effective approach to isolating and containing HLW and SNF because the rock has three important properties. First, water typically moves very slowly through clay. Second, clay can have a high sorption capacity for radionuclides. Third, any fissures or fracture planes in the rock close by themselves over the course of time. Three countries are actively investigating the possibility of developing a deep-mined geologic repository in clay formations found within their borders: Belgium (boom clay); France (argillite); and Switzerland (opalinus clay).

Although some important differences exist among the three countries' disposal concepts and the types of waste they will dispose of, the similarities in the disposal concepts are more substantial. For the purposes of the discussion below, Switzerland's national program is described (NAGRA 2002).

Disposal concept

The absence of significant advective groundwater flow in the clay means that radionuclides would move out of the engineered barriers and the undisturbed rock at a very slow rate. Any such movement would thus be controlled by diffusion, which suggests that only the most mobile and longest-lived radionuclides can reach the edge of the clay formation. Rock units surrounding the formation where a repository might be built, which also are rich in clay, would further slow the release of radionuclides to the biosphere. Chemical conditions in clay would be reducing, thereby maintaining the constituents of SNF in a low-solubility state.

Engineered barriers would be designed to work with the natural ones. The waste package would be constructed from steel and expected to prevent the inflow of water for several thousands of years. When the packages start to corrode, the resulting corrosion products might hydrolyze to create more acidic and aggressive near-field environments. The packages would be emplaced horizontally, and the drifts would be backfilled with bentonite. As with the crystalline rock disposal concept, the bentonite would retard the radionuclides and ensure that their transport is only by diffusion.

A separate but co-located, pilot facility would be constructed after a site for a deep-mined geologic repository is selected. Representative volumes of waste would be disposed of in this facility. Monitoring would take place to validate long-term predictions of how the host rock is evolving as well as to identify possible early indications of safety barrier failures.

Safety case

Like the German waste-management program, the Swiss program is intended to demonstrate that there will be zero releases for at least a million years if the host rock is undisturbed (NAGRA 2002). Only if there is significant climate change, borehole penetration of the repository, or deep groundwater extraction at the site would there be any release to the biosphere. Work to enhance the technical basis for the clay safety case continues, especially for repository performance under disturbed conditions. The following are some of the key uncertainties being explored:

- Solubility limits and sorption coefficients
- Rate at which the clay is resaturated
- Impact of heat on the performance of the bentonite buffer
- Gas generation by steel canister corrosion.

In creating its safety case, the waste-management program in Switzerland explicitly develops multiple lines of argument, including the use of alternative indicators that are complementary to those of dose and risk; natural analogues; and conservative performance assessments. Preliminary safety assessments using both deterministic and probabilistic methodologies have been carried out. Based on those assessments, the Swiss government has accepted the safety case advanced by NAGRA. The safety case also has been peer reviewed by an international team assembled by the NEA (NEA 2004c). The safety case also forms the basis for the *Sectoral Plan,* which currently guides efforts to identify suitable sites (SFOE 2008).

Unsaturated volcanic tuff

The United States is the only country that has developed a safety case for disposing of HLW and SNF in a deep-mined geologic repository located in unsaturated volcanic tuff. That safety case was developed by DOE in parallel with the characterization of a specific site located at Yucca Mountain in Nevada. The safety case rests on two main pillars. First, engineered barriers minimize the amount of water that can come in contact with the HLW and SNF. Second, transport of radionuclides to the biosphere is limited by the amount of water leaving the drifts (Abraham 2002).

View of Yucca Mountain from Busted Butte. Source: DOE.

Disposal concept

Very little precipitation falls on Yucca Mountain. A large fraction of what does returns to the atmosphere by evaporation, plant transpiration, and run-off; only a small amount of water infiltrates below the root zone, and even less seeps into the repository drifts. The location of the proposed repository lies in the unsaturated zone, where the environment is oxidizing, so the constituents of SNF would react with oxygen and become more mobile. To limit the release of radionuclides, corrosion-resistant titanium drip shields would be installed to divert the water that enters the drifts, thereby protecting the waste packages that lie underneath. The packages themselves would be fabricated with an outer layer of a nickel-based material, Alloy 22, and an inner layer of stainless steel. The packages would degrade very slowly in repository environments because of this corrosion-resistant alloy. Any radionuclides that escaped would move slowly because significant advective transport is unlikely.

Safety case

Relying on this disposal concept, DOE issued a final environmental impact statement (DOE 2002). That assessment was one of the reasons that Congress approved the selection of the Yucca Mountain site (U.S. Congress 2002). In June 2008, DOE submitted a license application to NRC based on a Total System Performance Assessment, which is grounded on more than 30 years of site-specific scientific and technical investigations.

Nonetheless, questions remain about the safety case for unsaturated volcanic tuff. Nearly 300 issues have been raised by supporters and opponents participating in the licensing hearing convened by the NRC. Moreover, the NWTRB, which is not a party to those hearings, has noted that there is only a poor understanding of how fast water moves in the unsaturated zone (NWTRB 2008, 30-31). It also has suggested that deliquescence-induced localized corrosion could lead to more-rapid waste package degradation than DOE maintains (NWTRB 2008, 25-28). These issues might eventually be resolved in the course of that hearing process. For the moment, at least, that hearing process has been suspended.

Table 2 presents a summary of the information contained in this section.

Table 2

SAFETY CASES FOR DISPOSING OF HLW AND SNF IN A DEEP-MINED GEOLOGIC REPOSITORY

HOST ROCK	COUNTRIES ADOPTING SAFETY CASE	FOUNDATIONS OF SAFETY CASE
Salt	Germany	Presence of salt implies the absence of flowing water. Fractures are self-sealing. High thermal conductivity and high acceptable design temperatures permit the construction of a small-footprint repository.
Crystalline rock	Sweden, Finland	Near-neutral, reducing groundwater thermodynamically precludes corrosion of elemental copper. Bentonite clay limits water contact with the waste package and retards the release of any radionuclides.
Clay	Belgium, France, Switzerland	Water typically moves very slowly through clays. Clay can have a high sorption capacity for radionuclides. Any fissures or fracture planes present in the rock close by themselves over time. Simplified design has no or small requirements for engineered barriers.
Unsaturated volcanic tuff	United States	Under current climatic conditions, limited amounts of rain fall on Yucca Mountain. Engineered barriers prevent the release of radionuclides to the natural system for a long time and release radionuclides slowly after penetration. Transport of radionuclides to the biosphere is limited by the amount of water leaving the drifts.

Major summary points

- Disposal concepts currently under consideration vary depending on the host rock within which the repository would be constructed.
- In all national programs, the disposal concept relies on both natural and engineered barriers. Concepts differ markedly in how much each barrier contributes to waste isolation and containment.
- Some disposal concepts, such as the KBS-3 approach to developing a repository in crystalline rock, are supported directly by fundamental physical principles. Others are supported by detailed modeling and analyses.

Substance and Adoption of Health and Safety Standards and Regulations

Health and safety regulations serve two purposes. They record society's views about what constitutes acceptable risk, and they establish mechanisms for certifying that an implementer's plan to develop a deep-mined geologic repository can, with a high degree of confidence, satisfy those requirements. All of the 13 national waste-management programs have put in place at least a rudimentary regulatory regime.

Substance of the regulations

As nations adopted geologic disposal as their preferred option for the long-term management of HLW and SNF, the question soon arose about what standards should govern that choice. Many of those involved argued that it is not the responsibility of the nuclear community to "purify" the earth by reducing the population's total exposure to radioactive materials. Thus they promoted the position that a repository need not sequester waste beyond the time when it becomes less hazardous than the uranium ore from which it was derived (see, for example, the discussion in NAS 1983). This simple approach has been replaced by more-sophisticated standards that focus on four specific issues.[30]

First, the regulators must decide on the length of the compliance period, the time over which the repository is expected to satisfy the protective standards. Regulators originally chose compliance periods of several thousand years. Now national programs in Belgium, France, Germany, Sweden, Switzerland, and the United States have selected compliance

[30] See Table 7 and the Detailed Tables in NWTRB 2009 for a more complete description of the regulations that have been adopted to date.

periods of at least 100,000 years and, in most of those cases, as much as 1,000,000 years. In the United Kingdom, the regulator requires the implementer to choose a compliance period and justify its choice.

Second, regulators impose dose constraints or risk limits or some combination of the two. Increasingly national waste-management programs have converged on similar dose constraints and risk limits, at least for the first few thousands of years that a repository is expected to isolate and contain HLW and SNF. Dose constraints vary between 0.1 and 0.3 millisieverts per year. Risk limits vary between a probability of 10^{-5} and 10^{-6} per year that death or serious health effects will arise over the course of the lifetime of an individual from exposure to radionuclides released from a repository. Beyond the first few thousand years, dose constraints may be also much as 1 millisievert per year and risk limits may be as low as 10^{-3} per year for some scenarios.

Third, the regulators decide how prescriptive their requirements should be. Those choices have produced considerable variation in how much direction the regulators provide. In some national programs, most notably the one in the United States, the rules are quite detailed, laying out specific requirements that the implementer must fulfill in order to get permission to construct or operate a deep-mined geologic repository. Among the specifics called for are the following (NRC 2001).

- Information that must be contained in an application to construct a repository
- Technical criteria for conducting preclosure and postclosure performance analyses, testing designs, and carrying out monitoring
- Requirements for evaluating the consequences of inadvertent human intrusion into a repository
- Types of institutional controls over the repository.

One of the ways that regulators defend the imposition of prescriptive requirements is by maintaining that they reduce the implementer's uncertainty.

In other national programs, such as the ones in Canada and Germany, the regulators simply require the implementer to provide information and to perform analyses in whatever manner it chooses. For example, in Germany, the implementer is told that "… a comprehensive safety case [must] be documented for all operating states of the final repository …" and that it must provide "… analysis and representation of the robustness of the final repository system … [along] with the reasons why this assessment is to be trusted …" (BMU 2010, 11-12). One of the ways that regulators defend the imposition of non-prescriptive requirements is by maintaining that they increase the implementer's flexibility.

Fourth, national programs differ in how compliance with the standards is to be demonstrated and what the requirements for demonstration are. In the Finnish, French, and German programs, a small set of scenarios is defined, and the implementer is required to evaluate deterministically how its proposed deep-mined geologic repository would perform. The regulators in the United States believe that the appropriate compliance methodology is a probabilistic performance assessment. Finally, the regulators in some countries, including Sweden and France, call for mixed approaches in which quantitative methods are used to evaluate performance early in the compliance period and more-qualitative methods are applied to later time periods. The Canadian regulators leave the choice of methodology completely up to the implementer.

Adoption of regulations

All national programs that have adopted specific regulations for the long-term management of HLW and SNF have done so in similar ways. Traditional mechanisms for public involvement are used. Most typically, the regulators themselves prepare a draft of the rules they want to adopt. Rarely will other interested and affected parties have the right to comment while the draft is being prepared.[31] Once it is completed, the regulators generally will release the proposed requirements for public comment. In some cases, the regulators convene open meetings where parties can ask the regulators questions and provide recommendations directly.

Regulators review the public input and determine what changes, if any, need to be made to the draft rules. Sometimes they also will prepare a document that explains why some suggestions were accepted and others were not. Once a final rule is published, it will take effect after a short period passes. In some countries, parties that disagree with the regulators' determinations can appeal to the courts. In the United States, this tactic tends to be used more often than not. Although courts there may overturn or remand regulations to their authors, the judiciary usually defers to the regulators' expert judgment as long as there is a reasoned basis for it.

National programs typically have put health and safety regulations into place *after* the implementer has begun to formulate its safety case or to identify candidate sites for a deep-mined geologic repository but *before* specific sites have been chosen. Some interested and affected parties may contend that revising regulations *after* a final site has been selected is inappropriate if the change process is not well explained and supported.

What transpired in the United States provides an instructive example of this dynamic. In response to Congress' passage of the 1992 Energy Policy Act, the Environmental Protection Agency and NRC issued Yucca Mountain-specific standards and regulations in the mid-2000s. Both agencies maintained that the new rules reflected the state-of-the art.[32] The State of Nevada, an opponent of the repository, claimed that the switch in approach was deliberately designed to aid in the licensing of the facility. In particular, the State argued that new technical information had come to light that, under one provision in the old—but not the new—rules, would have required the Secretary of Energy to disqualify the site (Miller 1996).[33] For some, this argument was made more persuasive because of DOE's deep involvement in the interagency process that reviewed the rules as the regulators were developing them (EPA 2005). Of course, sorting out motivations is never easy. For that reason, trust and confidence in the regulators may be compromised for at least some interested and affected parties if the process for changing rules is not completely transparent.

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[31] In the United States, regulators sometimes will publish an "Advanced Notice of Proposed Rulemaking" to solicit the views of interested and affected parties before the release of a draft regulation.

[32] The approach was recommended by NAS (NAS 1995).

[33] The provision involves limits on groundwater travel time from the repository to the accessible environment.

Major summary points

- National programs have adopted comparable health and safety standards and regulations. Some differences, however, exist both in the level of acceptable dose or risk and in the compliance period. The length of the compliance period typically has become much longer as the rules have evolved.

- A major difference between the regulatory process in the United States compared to most other countries is the requirement that a quantitative, probabilistic assessment of compliance with the standard must be presented. Compared to most other nations, the regulatory regime in the United States is very prescriptive.

- The process and rationale used to modify requirements can affect the public's trust and confidence in the regulator, especially once a site has been chosen for a deep-mined geologic repository.

Strategies for Identifying Candidate Sites for a Deep-Mined Geologic Repository

President Jimmy Carter's Interagency Review Group on Nuclear Waste Management (IRG) observed that site-selection strategies for a deep-mined geologic repository necessarily involve passing candidates through what is, in effect, two distinctly different "filters." On the one hand, detailed and quantitative technical requirements have to be met. On the other, sites could be disqualified because of considerations such as the "… lack of social acceptance, high population density, or difficulty of access." The two filters could be applied in any order. In the IRG's view, at least, although the suite of sites eventually selected might be different, depending on the order in which the filters were applied, "… equally suitable sites should emerge from either approach …" (IRG 1979 80; 81).[34] Over the years, the United States and other nations have initiated roughly two-dozen efforts to identify or to create processes for identifying potential repository sites. What is noteworthy is how varied those efforts have been.

Technical filter

Part of the variation stems from how the technical filter is constructed. In some cases, efforts to identify candidate sites have focused from the beginning on specific host-rock formations. The choice of those formations has been dictated either by constraints imposed by a country's geology or land-use patterns, by a view that particular host-rock formations possess distinctive advantages in terms of isolating and containing HLW and SNF, or by a

[34] As the IRG recognized, and as will be noted below, there is no unambiguous boundary that differentiates a "technical" from a "nontechnical" filter. At the margins, some overlap and interdependence may, even must, exist.

Determining the suitability of granite as a host rock. Source: SKB.

combination of these rationales. In Sweden and Finland, efforts were concentrated exclusively on the granitic formations of the Baltic Shield, which underlies the vast majority of both countries (Sundqvist 2002). In their early attempts to identify a candidate site, the United States and Germany looked only at locations in salt formations. The United States investigated sites near Lyons, Kansas, and in the Permian Basin in the southwest. The Germans chose a site at Gorleben. Because of the political turbulence surrounding the development of nuclear power, however, investigations at that site were suspended for 10 years. Those studies have been resumed recently (BfS 2010). The Swiss initially looked at sites in both crystalline rock and clay. Now only clay sites are being considered (SFOE 2008).

In other cases, efforts to identify candidate sites cast the net more broadly by enumerating generic qualifying and disqualifying conditions.[35] Qualifying conditions must be satisfied for a candidate site to be considered acceptable; disqualifying conditions eliminate a candidate sites from further consideration. In France, qualifying conditions included the depth of the repository horizon, the thickness of the host formation, the absence of natural resources, and present and future hydrogeologic flow patterns. In the United States, before the passage in 1987 of the Nuclear Waste Policy Amendments Act (NWPAA), both qualifying and disqualifying conditions for the preliminary screening of potential sites were elaborated in considerable detail (DOE 1984). The Canadians have advanced six "safety factors" that are likely to be used to evaluate candidate sites (NWMO 2009). In the Japanese screening approach, sites within a 15 km radius of the center of Quaternary volcanoes are rejected (NUMO 2004). Exclusionary screening criteria eliminate locations in England and Wales that are close to natural resources, such as fossil fuels and fresh water, as well as those within deep karstic formations and known source rocks for thermal springs (UKG 2008). In Germany, the AkEnd working group proposed seven qualifying conditions, which then were used to eliminate from consideration host-rock formations in five regions (AkEnd 2002).[36] Table 3 summarizes how the technical filter has been constructed in the two-dozen siting initiatives undertaken to date.

[35] Importantly, to date, no country uses a whole-system performance assessment to select the initial suite of candidate sites. At subsequent stages in the site-selection process, however, more holistic and systemic approaches are brought to bear.

[36] The recommendations advanced by AkEnd group were never adopted by the German Federal Government. Subsequently, the German Geological Survey concluded that crystalline rock formations in Germany were not suitable for development as a deep-mined geologic repository.

Table 3

COUNTRY	FOCUS ON HOST-ROCK FORMATION	QUALIFYING AND DISQUALIFYING CONDITIONS FORMALLY ADOPTED TO STRUCTURE THE SITE-SELECTION PROCESS
	TECHNICAL FILTER	
United States		
AEC: Lyons	Salt	None
ERDA: Permian Basin	Salt	None
IRG		Recommended that NRC establish siting criteria.
DOE: NWPA		DOE established detailed siting criteria.
DOE: WIPP	Salt	None
DOE: NWPAA	Tuff	DOE established new siting criteria.
Belgium	Clay	None
Canada		
AECL	Crystalline rock	None
NWMO		Proposed general siting criteria.*
China	Crystalline rock	National Nuclear Safety Administration established general siting criteria.
Finland	Crystalline rock	Radiation and Nuclear Safety Authority (STUK) established general siting criteria.
France		
CEA		No siting criteria established.
ANDRA	Crystalline rock and clay	Nuclear Safety Authority (ASN) established general criteria.
Germany		
Gorleben (1970s)	Salt	None
AkEnd		Proposed specific siting criteria.
Gorleben (2010)	Salt	None

*The Canadian Nuclear Safety Commission has issued guidance on siting a deep-mined geologic repository for HLW and SNF.

COUNTRY	FOCUS ON HOST-ROCK FORMATION	QUALIFYING AND DISQUALIFYING CONDITIONS FORMALLY ADOPTED TO STRUCTURE THE SITE-SELECTION PROCESS
	TECHNICAL FILTER	
Japan		NUMO proposed general siting criteria.
Republic of Korea	No decision made.	No decision made.
Spain	No decision made.	No decision made.
Sweden		
SKB: Pre-1992	Crystalline rock	None
SKB: Post-1992	Crystalline rock	None
Switzerland		
SFOE: Pre-2005	Crystalline rock and clay	None
SFOE: Post-2005	Clay	General siting criteria established.
United Kingdom		
UKAEA: 1970s		None
NIREX: Late 1980s	Wide variety of sedimentary and igneous rocks	None
NDA	Wide variety of sedimentary and igneous rocks	Siting criteria advanced as Government policy.

Nontechnical filter

Just as the construction of the technical filter introduces considerable variation in strategies for selecting candidate sites for a deep geologic repository, so does the construction of the nontechnical one. Arguably this filter's most important property relates to the power that a state or a community can exercise. In particular, the experience in the United States illustrates that the power need not be formalized in order to be effective. In 1971, the AEC proposed a site near Lyons, Kansas. Neither the state nor the local community—both of which opposed the selection—was given any explicit power to object. Nonetheless, opposition by the state contributed to a decision not to develop the site. Two years later, the Energy Research and Development Administration (ERDA) sought to investigate sites in the Salina Basin, which runs through Michigan, New York, and Ohio. Although the governors of those states did not have any formal authority, their opposition was sufficient to prevent any site investigations (Carter 1978).

Based on this experience, the IRG advanced the idea of "consultation and concurrence" in its recommendations to President Carter. Although this concept was never interpreted by the administration as offering a state the formal power to reject a site, as a practical matter, it did precisely that. In the IRG's draft report to the President, it observed that "…a state would be in agreement with each step of the [repository development] process before the next activity …" would begin (IRG 1979, 88). Later, "consultation and concurrence" evolved into the less potent concept of "consultation and cooperation," a formulation that was adopted in the 1982 NWPA. That legislation gave a state formal veto power over the selection of a site by the President, but the state veto could be overridden by a resolution approved by both houses of Congress. In the NWPAA, Congress mandated that only the Yucca Mountain site could be characterized, although it left unchanged Nevada's power to veto the President's recommendation, subject to an override by Congress.

Since the early 1990s, nations other than the United States increasingly have constructed their nontechnical filters in ways that significantly empower local jurisdictions. In Sweden, in the 1980s, SKB unilaterally identified potential sites and attempted to drill boreholes to test whether the sites are suitable for a deep-mined geologic repository. Subsequently, however, the implementer reconciled itself to the fact that the local communities have formal veto authority over the siting of infrastructure projects. Consequently, in the early 1990s, SKB issued a call for volunteers to host a repository. A number of communities responded positively, knowing that they held veto power over the final selection of a site. (Although the veto can be overridden by the national government, both political tradition and the legal constraints imposed make this an unlikely event.) A similar situation exists in Finland.

In France, districts and communities near Bure volunteered to host an underground research laboratory, knowing that it might become the forerunner to a repository. In Switzerland, now that technically suitable regions have been identified, cantonal commissions are being established to participate in decisions leading to the selection of at least two candidate sites. Although the presumption is that efforts will be made to resolve any conflicts that may arise, the final decision will rest with the Federal Council, subject to a possible national referendum.[37] Newly adopted processes for identifying candidate sites

[37] Before the process was changed in 2003, the referendum was held only in the canton where a repository might be sited.

in England and Wales in the United Kingdom, Japan, and Canada all require localities to volunteer even before paper studies of the local geology can be conducted.

Experience both in the United States and in other nations suggests that communities already hosting nuclear facilities or communities where benefits might make a significant economic or social difference may be especially receptive to being considered as a candidate repository site.[38] In Sweden and Finland, candidate sites were identified in communities where nuclear power plants operate. In Britain, borough and county councils in West Cumbria, where the Sellafield nuclear facilities are located, expressed an early interest in being considered a potential repository site. The state of Lower Saxony in Germany welcomed investigations of the Gorleben site. In the United States, the city of Carlsbad, New Mexico, aggressively sought to be considered as the location for WIPP as a means of bringing employment to the community.[39]

Focusing primarily on the nontechnical filter does not necessarily eliminate the frictions associated with identifying candidate sites for a deep geologic repository.[40] In Japan, the situation is very much in limbo. In 2002, Government launched a voluntary process. The mayor of the Toyo township in the Kochi Prefecture southwest of Tokyo announced that he would respond positively to NUMO's open solicitation. Opposition arose immediately within the local community and from governors of nearby prefectures. Ultimately the mayor was soundly defeated in an election that served as a referendum on participation in the site-selection process. No other community has stepped forward since. The Japanese government is now suggesting that alternatives to a voluntary approach may have to be considered. In the United States, although two of the three candidate sites identified for the first repository under the NWPA were "nuclear communities," governors of the two states where they were located announced their intense opposition, and both made clear that they would exercise a veto if the site in their site were chosen for development.[41]

Table 4 summarizes how the nontechnical filter has been constructed in the two-dozen siting initiatives.

Interdependence of the filters

The two filters are not independent of each other, except in some abstract or theoretical sense. The construction of the nontechnical one may affect the technical one in important ways. To begin with, applying the technical and nontechnical filters is not purely mechanical nor can it typically be programmed neutrally. In the United States, to consider just one example, the technical content of the 1984 siting guidelines (10 CFR 960) was constrained by language in the NWPA and was profoundly influenced by an

[38] These communities always make clear that their continued interest depends on being convinced that a repository would operate safely.

[39] Only defense-origin transuranic waste can be disposed of at WIPP under present regulations and agreements. However, because that facility is the only operating deep-mined geologic repository, its story may be instructive for efforts to site a facility for HLW and SNF.

[40] Many analysts and commentators, for instance, point to the success of the siting process in Sweden and argue that it should be emulated elsewhere. Although the process may work well in Sweden, the Swedish model has not (yet) been successfully replicated in any of the other countries that have consciously adopted it (IAEA 2007).

[41] The Japanese and the American examples illustrate the so-called "donut effect," in which a local community willing to host a deep geologic repository can be blocked by officials representing governments at the state or regional level.

Table 4

NONTECHNICAL FILTER				
COUNTRY	**EARLY STATE OR LOCAL INVOLVEMENT IN THE PROCESS**	**VOLUNTEER**	**NUCLEAR COMMUNITY**	**BENEFITS PACKAGE**
United States				
AEC: Lyons	None	No	No	None
ERDA: Permian Basin	None	No	No	None
IRG	Non-site specific process.	Proposed consultation and concurrence.	Not applicable	Not applicable.
DOE: NWPA	None	No	Two nuclear communities were among the three final sites selected.	Benefits package could be negotiated.
DOE: WIPP	Informal	Carlsbad community expressed willingness to host facility. New Mexico did not object.	No	Benefits package received.
DOE: NWPAA	None	No	Yes	Benefits package could be negotiated.
Belgium	No decision made.	No decision made.	No decision made.	No decision made.
Canada				
AECL	Non-site specific process.	Not applicable.	Not applicable.	Not applicable.
NWMO	Extensive	Yes	No decision made.	No decision made.
China	No decision made.	No decision made.	No decision made.	No decision made.
Finland	Yes	Did not veto selection.		
France				
CEA	No	No	No	No
ANDRA	Yes	Volunteers were sought to host an underground research laboratory.	No	Benefits package was received.
Germany				
Gorleben (1970s)	Yes.	Yes	No	Benefits package received.
AkEnd	Non-site specific process.	Not applicable.	Not applicable.	Not applicable.
Gorleben (2010)	Yes	Yes	No	Benefits package is available.

NONTECHNICAL FILTER				
COUNTRY	**EARLY STATE OR LOCAL INVOLVEMENT IN THE PROCESS**	**VOLUNTEER**	**NUCLEAR COMMUNITY**	**BENEFITS PACKAGE**
Japan	Yes	Volunteer unsuccessfully sought for the last eight years	No decision made.	Benefits package is available.
Republic of Korea	No decision made.	No decision made.	No decision made.	No decision made.
Spain	No decision made.	No decision made.	No decision made.	No decision made.
Sweden				
SKB: Pre-1992	No	No	No	No
SKB: Post-1992	Yes	Originally eight communities volunteered for feasibility studies to evaluate whether they would be prepared to host a repository. Two of the communities volunteered to host a repository.	Yes	Benefits package was negotiated in which the community **not** selected to host a repository would receive three-quarters of the total.
Switzerland				
SFOE: Pre-2005	No	No	No	No
SFOE: Post-2005	Communities will be consulted as part of Phase I of the Sectoral Plan.		No decision made.	No decision made.
United Kingdom				
UKAEA: 1970s	No	No	No decision made.	No
NIREX: Late 1980s	No	No	Yes	No
NDA	Yes	Borough and county councils located near the Sellafield site have expressed an interest in possibly hosting a repository.	Yes	Benefits package is available.

administrative rulemaking process, in which states sought to include guidelines that would lead to the disqualification of sites within their borders.[42] In addition, using those guidelines to narrow the nine potential sites to five sites, which would be evaluated, to three sites, which would be characterized, revealed how difficult it can be to implement even an ostensibly objective and technical process (DOE 1986a; Merkhofer and Keeney 1987). The evaluation of the qualifying and disqualifying conditions was open, perhaps unavoidably, to considerable interpretative flexibility. Moreover, by focusing on selective and discrete attributes of a candidate site, the performance of the total repository system never received appropriate attention.

Further, implicit in a voluntarist approach is the presumption that a very wide range of geologic features and locations are suitable or can be made suitable. In some cases, this presumption is well-founded. In both Sweden and Finland, the Baltic Shield is so pervasive that sites throughout both countries likely could be found to develop a repository. Similarly, in the United States, the salt formations of the Salina and Permian Basins are so extensive that many locations could be considered. In other cases, even after taking into account fairly general disqualifying conditions, potential disconnects may very well arise, so that applying *both* the technical and the nontechnical filters yields a null set of potentially suitable and acceptable sites. For many countries, including the United States under the NWPA and Switzerland, applying the technical filter rigorously at the start is viewed as a prerequisite for creating a credible process for identifying candidate sites for a deep geologic repository. Yet, in the former instance, Congress halted characterization of any site other than Yucca Mountain. In the latter one, the final outcome is still to be determined.

Sequencing

An additional source of variation among national programs can be traced to policies that govern the sequence for accepting or rejecting a candidate site. In the United States, a "serial" policy was at first adopted. Sites would be evaluated formally one by one until a suitable site was found. The Carter Administration, however, proposed a "parallel" approach, in which at least two candidate sites would be characterized simultaneously and compared. This recommendation was ratified in the NWPA. Several years later, Congress returned to a serial policy with the passage of the NWPAA, which singled out Yucca Mountain in Nevada as the sole site to be characterized. Although several sites were informally considered in Germany during the 1960s and 1970s, the Gorleben site was the only one investigated seriously. Despite a clear call for communities to volunteer, the government in the United Kingdom has received an expression of interest from only one group of local governments. Thus, the opportunity to compare candidate sites may never materialize. Conversely, the Swiss mandate the parallel characterization and comparison of at least two sites. In Sweden and Finland, sites in two and four municipalities respectively were investigated in comparable detail.[43] In France, more than 30 sites were studied before 1990. Legislation passed in 1991 required the comparison of a clay site and a

[42] See, for example, comments on the proposed 10 CFR 960 from the State of Nevada suggesting that oxidizing conditions should disqualify a proposed site and comments from the State of Mississippi seeking to limit the ability of DOE to site a repository in salt domes.

[43] In Sweden, the two detailed investigations had been preceded by feasibility studies in eight communities, resulting in the identification a total of eight sites in five communities as having the potential for detailed investigation.

crystalline rock site. Finding an appropriate site in crystalline rock was not possible, so an actual clay site was ultimately contrasted with a hypothetical crystalline rock site. Finally, in several countries, including Canada, Belgium, China, and Britain, no explicit decision has been made about using a serial or a parallel approach.

Table 5 summarizes how the filters have been or are being applied by the 13 nations considered in this report.

Major summary points

- National programs must balance specificity and generality in constructing technical filters. More-specific qualifying and disqualifying conditions reduce the number of potential candidate sites but provide explicit guidance on a technical basis for their selection. General qualifying and disqualifying conditions allow more sites to be considered but typically provide only a generic technical basis for their selection.
- Many national programs seek to identify a suite of candidate sites so that they can be compared. This objective has not always been met. No country to date has fully characterized at depth more than one site.
- Although the process for identifying candidate sites appears clear and accountable, in practice it has proven to be cumbersome. The overwhelming majority of efforts have not succeeded. In many cases, the underlying cause of failure has been an inability to integrate the application of the technical and nontechnical filters, the most important of which is public support or opposition.

Table 5

PROCESSES FOR SELECTING CANDIDATE SITES FOR A DEEP-MINED GEOLOGIC REPOSITORY				
COUNTRY	**APPLICATION OF THE FILTERS**	**CHALLENGES ENCOUNTERED**	**OUTCOME**	**SERIAL OR PARALLEL EVALUATION OF SITES**
United States				
AEC: Lyons	Technical filter was applied.	State opposition led to Congress to deny appropriations.	Site was abandoned.	Serial
ERDA: Permian Basin	Technical filter was applied.	State opposition arose.	Sites were never investigated.	Serial
IRG	Asserted that order in which the filters were applied did not matter.	Proposals were generally accepted.	Most proposals were incorporated into the NWPA.	A parallel approach was proposed.
DOE: NWPA	Technical filter was applied.	Costs of site characterization rose; political opposition from final three candidate states intensified.	Congress amended the NWPA to allow only the Yucca Mountain site to be characterized.	Parallel
DOE: WIPP	Nontechnical filter was applied once the AEC had identified salt as a favorable generic host-rock formation.	Local community supported the selection of the site, overcoming opposition from the Carter Administration.	WIPP began accepting waste from the DOE defense complex in 1999.	Serial
DOE: NWPAA	Nontechnical filter was applied.	State of Nevada opposed the selection of Yucca Mountain.	Administration moved to withdraw license application in 2010. Litigation is ongoing at the NRC and in the courts.	Serial
Belgium	No decision made.	Not applicable.	Not applicable.	No decision made.
Canada				
AECL	Technical filter was applied first.	Disposal concept was deemed socially unacceptable.	National waste-management program was reconstituted.	No decision made.
NWMO	General siting criteria are used to identify areas that might be suitable; eight volunteer communities have expressed an interest in learning more about the possibility for hosting a repository.	Adaptive Phased Management approach generally accepted.	Siting process has been initiated.	Depends on the number of volunteers.
China	Technical filter was applied.	No challenges have emerged to date.	Process is continuing.	No decision made.
Finland	Technical filter was applied; negotiations with communities took place.	Few challenges were encountered to date.	Site at Eurajoki is being developed for a repository.	Parallel
France				
CEA	Technical filter was applied first.	Political opposition arose.	Sites were never investigated.	Serial
ANDRA	Nontechnical filter was applied.	Few challenges were encountered to date.	Underground research laboratory established in Meuse/Haute-Marne region; nearby a repository is being developed.	Parallel in theory; serial in practice.

Table 5, continued

PROCESSES FOR SELECTING CANDIDATE SITES FOR A DEEP-MINED GEOLOGIC REPOSITORY				
COUNTRY	**APPLICATION OF THE FILTERS**	**CHALLENGES ENCOUNTERED**	**OUTCOME**	**SERIAL OR PARALLEL EVALUATION OF SITES**
Germany				
Gorleben (1970s)	Technical filter was applied to select salt as the generic host rock. State of Lower Saxony proposed the specific site.	Although the local state was initially supportive, difficulties arose at the national level following the 1998 federal election.	Site investigations were suspended for 10 years.	Serial
AkEnd	Proposed a set of site-selection criteria to winnow down the number of potential sites; negotiations with communities would follow.	Political support for proposal never developed.	Proposal was never adopted as national policy.	Parallel
Gorleben (2010)	Application of technical filter was resumed in October 2010.	Political opposition has arisen, but it is too early to know how intense and sustained it will be. Both the Federal and Lower Saxony governments support the construction of a deep-mined geologic repository at Gorleben.	Unclear	Serial
Republic of Korea	No decision made.	Not applicable	Not applicable	No decision made.
Spain	No decision made.	Not applicable	Not applicable	No decision made.
Sweden				
SKB: Pre-1992	Technical filter applied.	Political opposition arose.	Sites were never investigated.	No decision made.
SKB: Post-1992	Nationwide search held for a community that would allow site investigations.	Many communities volunteered in the initial round. Two communities remained in contention until the end of the process.	Site in Östhammer is being developed for a repository.	Parallel
Switzerland				
SFOE: Pre-2005	Technical filter applied.	Criticism arose that there was no comparison of sites.	Government accepted the disposal concept but required site comparisons.	Serial
SFOE: Post-2005	Technical filter being applied to be followed by the application of the nontechnical filter.	Few challenges have been encountered to date.	Unclear	Parallel in theory.
United Kingdom				
UKAEA: 1970s	Technical filter to be applied first.	Planning permission was difficult to obtain.		
Nirex: Late 1980s	Technical filter to be applied first.	Planning permission was denied.		
NDA	General siting criteria will be used to identify areas that might be suitable.	No overt opposition to process.	Two adjacent communities are discussing with Government the possibility of participating formally in the Managing Radioactive Waste Safely process.	Depends on the number of volunteers communities.

Site Selection for a Deep-Mined Geologic Repository

In all national programs, the implementer is responsible for proposing a site for development as a deep-mined geologic repository. In some cases, political ratification at the national level of that decision also must take place.

The implementer's decision

If only one site has been fully characterized at depth, as is the case in the French and American programs, it will be proposed by default if the implementer believes it to be suitable. Canada, Japan, and the United Kingdom, which have adopted, at least in principle, a parallel approach to identifying candidate sites, have not specified how the implementer will choose among multiple suitable sites. The implementer in Switzerland has been given only the most general instructions for making its decision (SFOE 2008, 64).

> [The implementer shall] select the site for repository construction from the sites that have been integrated into the *Sectoral Plan* as an interim result. To be able to make and justify this selection, the level of knowledge for the different sites has to sufficient to allow a comparison to be carried out… The results—together with the evaluation of further aspects in accordance with the conceptual part of the *Sectoral Plan*—lead to an overall evaluation for site selection by the [implementer].

Implementers in Finland and Sweden, however, did decide among several candidate sites. Moreover, in the United States, before Congress only permitted the characterization of Yucca Mountain, DOE narrowed candidate sites from nine to five to three.

Finland

Posiva Oy used the environmental impact assessment process to document its choice of Olkiluoto site in Eurajoki over Romuvaara in Kuhmo, Hästholmen in Loviisa, and Kivetty in Äänekoski (Posiva Oy 1999). The assessment considered the following eight criteria.

- Long-term safety
- Constructability
- Possibilities to expand the repository
- Operation of the final disposal facility
- Social acceptance
- Land use and environmental loading
- Infrastructure
- Costs.

SKB informs the mayors from two candidate municipalities of its site-selection decision. Source: SKB.

Although the four sites have different geologic properties, they did not differ appreciably in terms of their long-term ability to isolate and contain SNF. Nor did the sites differ substantially in the geotechnical work needed to build the facility, the ease in which it could be expanded, infrastructure requirements, or costs. Because Eurajoki and Loviisa host nuclear power plants, their residents were less fearful of the transport of SNF through their communities and were more generally accepting of a repository. Developing a deep-mined geologic repository in Kuhmo and Äänekoski would significantly transform heavily forested areas. In the final analysis, Posiva chose the Eurajoki site over the Lovissa one based on economic and development considerations rather than for technical reasons.

Sweden

In 2009, SKB compared a site at Forsmark in Östhammar with a site at Laxemar in Oskarshamn (SKB 2009). Both communities strongly support the placing of a deep-mined geologic repository within their boundaries. SKB thus could focus its decision-making solely on the following technical factors:

- Safety-related site characteristics
- Technology for execution, i.e. the prospects for carrying out the project as robustly and efficiently as possible
- Occupational health and environmental impact
- Societal resources.

SKB did not accord these considerations equal weight. “In the event the analyses do not show a clear difference between the sites, the site that offers the best prospects for long-term safety is selected …” (SKB 2009, 57).

SKB ultimately chose the Östhammar site because it possessed superior characteristics in comparison to the site at Oscarshamn. According to SKB, important differences in the permeability of fractures in the bedrock and somewhat smaller differences in the projected future composition of the groundwater created significant differences in the safety assessments of the two sites. Further, significant future reduction in the salinity of the groundwater at either site could result in degradation of the bentonite, raising the possibility of sulphide-induced corrosion of the copper waste packages. Because groundwater flow is considerably lower at Östhammar, fewer packages would be damaged. At the margins, Östhammar also was preferred because constructing a repository would be easier, and the environmental impacts would be lower. No political ratification of SKB’s decision to base its license application on the site located in Östhammar was required.

United States

Under the NWPA, DOE was required to recommend to the President a suite of sites for detailed characterization. After a long and contentious public process, DOE issued site-suitability guidelines (DOE: 1984). It prepared environmental assessments for five potential sites. The analyses contained a common chapter that presented rankings of each site in relation to the guidelines. Initial attempts to aggregate the rankings were sharply criticized by the NAS (Parker 1985a). DOE then decided to use a decision-aiding methodology, multiattribute decision analysis (MUA), in the hope of obtaining greater agreement on how the five sites would be down-selected to three (DOE 1986a [published report]). A second peer-review by the NAS strongly supported the use of the methodology but declined to address the ultimate ranking or recommendation of specific sites for characterization (Parker 1985b). Simultaneously with the release of the MUA report, the Secretary of Energy determined that Yucca Mountain, a salt site in Texas, and a basalt site in Washington would be investigated (DOE 1986b).

The three sites chosen by the Secretary were not the top three identified by the MUA. Considerable public controversy arose, with some parties accusing DOE of manipulating the technique to produce pre-ordained outcomes. In response, DOE stated that the MUA was a “decision-aiding” not a “decision-making” methodology. For example, the methodology did not capture considerations, such as geologic diversity, that the implementer might consider crucial. Of equal importance was the exclusion from the MUA of other considerations, including the degree of local opposition to a repository, risk perceptions associated with transportation of HLW and SNF, geographic equity, and licensability (Merkhofer and Keeny 1987). In short, even the most sophisticated methodology for selecting a site for a deep-mined geologic repository is unlikely to produce agreement if local or state governments believe that the choice is being imposed on them.

Political ratification

Canada

Under the Canadian approach of Adaptive Phased Management, volunteer communities are being sought to host a deep-mined geologic repository. If more than one locality accepts and if the technical suitability of the sites is established, a public-engagement program would be launched to consult with interested and affected parties. Safety evaluations and site-specific designs would be prepared. Environmental impact assessments would be developed. Once the Federal Minister of the Environment approves the impact assessments, NWMO would be allowed to apply to the regulators for a Site Preparation License.

Finland

Under the Nuclear Energy Act, an application for a decision-in-principle must be submitted before a site for a deep-mined geologic repository can be approved. The application was filed in 1999 and included statements from the four municipalities under consideration as well as statements from surrounding municipalities. All of the statements were strongly supportive. In addition, the regulator performed preliminary safety assessments. A public hearing then was held. Following the hearing, the Council of State rendered the decision-in-principle in 2000 agreeing to the selection of the site in Eurajoki. The decision-in-principle was confirmed by the Parliament the following year.

France

Although only locations in the Meuse/Haute-Marne region have been studied, a site there for a deep-mined geologic repository cannot be selected simply by default. The 1991 legislation required that public hearings be held on the progress made in each of the four research areas being pursued by ANDRA (OPECST 2005). Subsequently, the Parliament took up the issue and in 2006 passed the Sustainable Management of Radioactive Materials and Waste Act. Among other things, the law authorizes additional studies directed toward selecting a site in the vicinity of the village of Bure. By 2005, ANDRA had designated a 250 km^2 area “transposition zone” within which it believed a deep-mined geologic repository could be constructed. Recently ANDRA identified a 30 km^2 area where it will propose to construct the repository’s underground works. Discussions are ongoing with the local communities to determine where the repository’s surface facilities would be built. Parliament will reach a decision about the site in 2016 after an organized public debate.

Japan

Because no volunteer community has come forward yet, NUMO has not outlined in detail how it intends to select a site for a deep-mined geologic repository if several candidate locations are deemed suitable. The expectation, however, is that an environmental impact assessments would be prepared. Under the Final Disposal of Specific Radioactive Wastes

Act, after the Cabinet consents to NUMO's recommendation, the Minister of Economy, Trade, and Industry would need to give formal approval.

Switzerland

Site selection is Stage Three of the *Sectoral Plan*. In that stage, NAGRA would investigate candidate sites in greater detail. With the involvement of the siting region, socioeconomic impacts would be studied. Any benefits package that must be provided would be negotiated and made transparent. Stage Three culminates in the preparation of a general license to construct the deep-mined geologic repository and an environmental impact assessment. The Federal Council would determine whether the general license should be approved; if it is, the Council's decision would have to be ratified by the Parliament. A national referendum may be called, the outcome of which could overturn the parliamentary action.

United Kingdom

Under the Managing Radioactive Waste Safely program, decision-making bodies in local communities would decide whether to proceed to each step in the site-selection process. That determination would be made based on the technical investigations carried out by the British Geological Society as well as the outcome of negotiations over a benefits package. Government would make the final decision about which technically suitable site to choose if more than one locality agrees to host a deep-mined geologic repository, or it would affirm (or reject) the selection of a site if only one community reaches the end of the process.

United States

Although only the site at Yucca Mountain has been characterized, the NWPA still requires that a political process be followed before the site can be officially selected. That process unfolded in 2002. At the beginning of the year, the Secretary of Energy recommended to President George W. Bush that Yucca Mountain be approved for development of a deep-mined geologic repository. The President approved this recommendation the next day and notified Congress. Under the law, the Governor of Nevada had 90 days to veto the selection of the site, which he did. Congress held hearings during the spring and passed a Joint Resolution that overrode the Nevada veto and officially selected Yucca Mountain as the site of a deep-mined geologic repository (U.S. Congress 2002).

Major summary points

- Selecting a site for a deep-mined geologic repository is likely to be less controversial in countries that rely on a voluntarist approach for identifying candidate sites.
- Although the implementer is always responsible for proposing where a deep-mined geologic repository might be located, in most countries, some form of political ratification is required at the national level before a site for a deep-mined geologic repository can be selected.

Approval to Construct a Deep-Mined Geologic Repository

The processes involved in obtaining approval to construct a deep-mined geologic repository are as varied as the processes involved in identifying candidate sites. In most countries, a representative body, such as the legislature or the Government, makes the final decision. Typically, that body relies on the regulators' advice. In some countries, however, the regulators make the final determination of whether the proposed repository system complies with established requirements. The discussion below of arrangements established in several countries describes the range of variation.

Canada

Under the current law, the Canadian Nuclear Safety Commission (CNSC) would become involved only when an application for a Site Preparation License is submitted, although the regulators expect to provide comments to NWMO and the public during the siting process. It is entirely up to the implementer to determine the appropriate methodology for demonstrating that dose constraints and risk limits can be met. Scoping assessments, bounding assessments, and realistic calculations are all methodologies that the regulator finds acceptable. The assessments can be either deterministic or probabilistic (CSNC 2006). Under the Nuclear Safety and Control Act, the CNSC must hold public hearings before making its decision. Beyond that requirement, the regulators' decision-making process is both completely internal and final.

Finland

STUK has been actively involved in the process that will likely culminate in the submittal of a license application by Posiva in the next few years. It reviewed Posiva's preliminary safety assessments in 1996, 2006, and 2008 as well as the implementer's siting program in 2001. STUK also has conducted periodic evaluations of the implementer's research and development plans.

STUK requires that Posiva demonstrate the long-term safety of a deep-mined geologic repository by means of a safety analysis. That analysis must address expected evolutions and unlikely disruptive events. Numerical calculations may be complemented by qualitative expert judgment whenever the quantitative analyses are not feasible or are too uncertain. The safety assessment may be either deterministic or probabilistic. Uncertainties and their importance to safety are assessed in separate analyses (Finnish Council of State 2008). No requirements for public involvement in the regulators' deliberations have been established. STUK only makes recommendations to Government, which holds the final authority to issue a license.

France

According to the 2006 Radioactive Materials and Waste Planning Act, following the public debate and selection of a site, ANDRA will prepare and submit a license application to construct a deep-mined geologic repository. The application will be reviewed by ASN and the CNE. ASN will be aided in its review by a technical support organization, the Institute for Radiation Protection and Nuclear Safety. The ASN requires ANDRA to demonstrate compliance through the deterministic evaluation of several nominal and disruptive scenarios. In addition, deterministic sensitivity calculations are used to evaluate the effect of uncertainty on repository performance.

The passage of the Transparency and Nuclear Security Act in 2006 gave new powers to communities near nuclear power and fuel cycle plants. Local information committees (CLIS) were given the right to obtain information on the operation and management of those facilities. Armed with that information, the CLIS also will comment on ANDRA's license application, as will the municipalities, districts, and regions affected by the repository project.

The views of ASN, CNE, and the CLIS are sent to OPECST, which, in turn, conveys them to the relevant committees of the National Assembly and the Senate. Subsequently, Government must table a bill prescribing relevant reversibility conditions. Once that law is passed, the license application may be granted by State Council decree after another public debate is held. The application cannot be granted if the satisfaction of the reversibility decree "is not guaranteed."

Germany

The implementer, the Federal Office of Radiation Protection, would submit an application—including a safety evaluation and an environmental assessment—to the licensing authority of the Land (State) where the proposed repository would be located. The safety evaluation would use deterministic calculations. These calculations would rely on realistic models that use, for example, median values of input parameters. The Nuclear

Licensing Procedures Ordinance specifies how the public can be involved. Relevant technical documents must be made available and interested parties have the right to raise objections in writing. The Länder (States) would hold the initial authority for Plan Approval, the procedure that governs whether such a deep-mined geologic repository can be constructed. The federal Ministry for the Environment, Nature Conservation, and Nuclear Safety, however, has the right to instruct the Plan Approval Authority to issue a license. Decisions by the Länder can be appealed in court by both the applicant and opponents to the facility.

Sweden

Permits issued under two pieces of legislation, the Nuclear Activities Act and the Environmental Code, are required before a deep-mined geologic repository can be constructed.[44] Both laws instruct SKB to prepare a safety evaluation and an environmental assessment. The evaluation can be developed using a variety of methodologies; deterministic and probabilistic approaches are equally acceptable. SKB submitted its license application in March 2011.

SSM will process the license application under the provisions of the Nuclear Activities Act and submits its views to Government. At roughly the same time, an Environmental Court will review the application under the Environmental Code, holds a public hearing, and issues a statement of comment for both the Government and the host-community. Government will then ask the municipalities that would host the facilities whether they are prepared to accept them. If the municipalities agree, Government decides whether the application is "permissible" under both laws. SSM grants a license under the Nuclear Activities Act and the Radiation Protection Act, which may include stipulations and conditions. The Environment Court grants a license under the Environmental Code, which can also include stipulations and conditions.

Public participation is secured in various ways. Although SSM relies mostly on written statements from interested and affected parties, it can hold hearings if it so chooses. The proceedings of the Environmental Court are open, and interested and affected parties can attend and make statements.

United Kingdom

The disposal of HLW and SNF in a deep-mined geologic repository is currently regulated by the Environment Agency under the Radioactive Substances Act of 1993.[45] Depending on the enactment of new legislation that is currently under consideration, two potential routes for reaching a regulatory determination on authorizing a deep-mined geologic repository are conceivable. Under a procedure based solely on a "process of agreement," the regulator would provide advice during the period that the implementer is developing the facility. However, regulatory control would start after repository construction but before waste emplacement. Under a staged regulatory process, control would begin as soon as underground investigations start (Environment Agency 2009). At various steps along the repository development process, the regulators would issue permits and licenses. Although

[44] See, National Council for Nuclear Waste 2007 for a good discussion of the licensing process.

[45] The Nuclear Installations Inspectorate will regulate operational activities at a repository.

guidance has been issued, no decision has been made about what the implementer must do to demonstrate compliance with established dose constraints or risk limits.

Although it is expected that the implementer would engage in continual dialogue with potential host communities, the regulator also would be involved. Proactive efforts would be devised to engage interested and affected parties. Ultimately, the final decision would rest with the regulators, who have broad discretion to accept or reject outside input in order not to "… compromise [their] regulatory independence" (Environment Agency 2009, 36).

United States

NRC has erected an elaborate structure for determining whether a license to construct a deep-mined geologic repository should be issued. Not only has NRC established highly prescriptive technical requirements, but it also has set forth an intricate process that formally begins once a license application has been submitted. Yet the process in the United States probably offers more opportunities than any other country for interested and affected parties to participate meaningfully in regulatory decision-making.

The regulatory staff first determines whether the application contains sufficient information to permit a meaningful review (NRC 1989). It then begins to evaluate the safety claims advanced by DOE. In particular, it scrutinizes the technical basis for the safety assessment, which must include calculating the long-term performance of the deep-mined geologic repository using a probabilistic methodology.

In parallel, an independent licensing board conducts an adjudicatory hearing. The hearing format gives admitted parties the right to advance contentions that document disagreements with DOE's claims.[46] Further, the format allows those parties to present witnesses, to carry out discovery of documents held by other parties, and to cross-examine witnesses called by other participants. The licensing board is required to base its decision on whether a license should be granted solely on the information brought forward at the hearing. The board's decision can be appealed to the full Commission and to the courts.

Major summary points

- In most national programs, the regulatory requirements for determining whether the construction of a deep-mined geologic repository should be permitted are typically not prescriptive. The United States is an exception to this general rule.
- Final decisions about permitting the construction of a deep-mined geologic repository can be made by Government or by the regulators, depending on country-specific circumstances.
- National waste-management programs offer varying opportunities for interested and affected parties to influence the regulatory process.

[46] It was at this point in the process that NRC's consideration of the Yucca Mountain license application was suspended. It is unclear whether or when the proceedings will resume. Therefore, the discussion that follows reflects only the process that has been put in place.

Conclusion

In each of the 13 national programs considered in this report, the long-term management of HLW and SNF has proven more complicated and protracted than initially expected. What was formerly viewed as a relatively simple technical task is now recognized as a complex socio-technical problem involving political negotiations and institutional design challenges as well as path-breaking scientific and technical analyses. Nonetheless, several national programs already have made considerable progress. Sites for a deep-mined geologic repository for HLW and SNF have been selected in four countries—Finland, France, Sweden, and the United States. License applications to construct such a facility have been submitted in two of those nations (the U.S. and Sweden). Applications are likely to be submitted in the other two within the next few years.

The information contained in this report suggests several important conclusions about processes used to develop a deep-mined geologic repository.

- *It is possible to elaborate a disposal concept and to advance a safety case, including quantitative performance assessments, that are widely credible not only to scientific and technical communities but also to broad segments of the general population and political leaders.* It appears as if a deep-mined geologic repository can be developed in a number of different hydrogeologic environments. An open and transparent technical assessment process, including international peer reviews, increases public and political support.
- *It is possible to find communities that are willing to host a deep-mined geologic repository.* From the experience gained in countries where sites have been selected, it appears that some communities do so because of their familiarity with other nuclear activities; others do so because of the economic benefits that might accrue in the future. All of those communities, however, were given a meaningful say in the site-selection process. And all of those communities came to be convinced by the respective implementers that the facility could be operated safely.[47]

[47] In Federal systems, such as those found in Japan and the United States, it may be necessary to secure the approval of a politically superior state or prefecture. This requirement may complicate any voluntary process.

- *Although national programs differ in terms of what is considered an acceptable risk and how to demonstrate whether a deep-mined geologic repository satisfies those standards, international views on these matters are converging.* At least for the first few thousands of years after repository closure, dose constraints across countries are within a factor of three of each other and risk limits are within a factor of ten. Only for compliance periods on the order of 100,000 or 1,000,000 years has no international consensus yet been formed on dose constraints, risk limits, and methodology.
- *Organizational forms differ significantly across countries, but successful ones have several characteristics in common.* Nuclear industry-owned corporations have been successful in Sweden and Finland. A government agency has been successful in France. Rather than organizational form *per se*, what appears to be important are organizational behaviors, such as leadership continuity, funding stability, and the capacity to inspire public trust and confidence over long periods of time.

Today, more than a half-century after electricity was first produced by splitting the atom, the beneficiaries of that energy source have committed themselves to finding ways to manage the radioactive wastes thereby created in a technically defensible and socially acceptable way. That commitment should be a source for optimism, not only for the generation that produced the wastes, but for succeeding generations as well.

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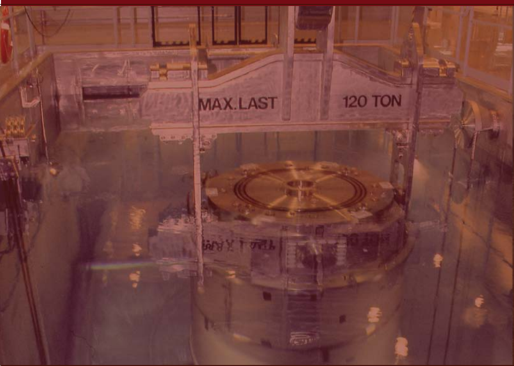
Acronym List

AEC	Atomic Energy Commission (United States)
AECL	Atomic Energy of Canada Limited
ANDRA	National Radioactive Waste Management Agency (France)
ASN	Nuclear Safety Authority (France)
CEA	Atomic Energy Commission (France)
CLI	Local Information Committees (France)
CNE	National Review Board (France)
CNSC	Canadian Nuclear Safety Commission
CoRWM	Committee on Radioactive Waste Management (United Kingdom)
DBE	German Service Company for the Construction and Operation of Waste Repositories
DOE	Department of Energy (United States)
ERDA	Energy Research and Development Authority (United States)
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency (United Nations)
IRG	Interagency Review Group on Nuclear Waste Management (United States)
MUA	multiattribute utility analysis
NAGRA	National Cooperative for the Disposal of Radioactive Waste (Switzerland)
NAS	National Academy of Sciences (United States)
NDA	Nuclear Decommissioning Authority (United Kingdom)

NEA	Nuclear Energy Agency (Organization for Economic Cooperation and Development)
NRC	Nuclear Regulatory Commission (United States)
NWF	Nuclear Waste Fund (United States)
NUMO	Nuclear Waste Management Organization (Japan)
NWMO	Nuclear Waste Management Organization (Canada)
NWPA	Nuclear Waste Policy Act (United States)
NWPAA	Nuclear Waste Policy Amendments Act (United States)
NWTRB	Nuclear Waste Technical Review Board (United States)
OPECST	Parliamentary Office for the Evaluation of Science and Technology Options (France)
SKB	Swedish Nuclear Fuel and Waste Management Company
SNF	spent nuclear fuel
STUK	Radiation and Nuclear Safety Authority (Finland)
SSM	Radiation Safety Authority (Sweden)
UKAEA	United Kingdom Atomic Energy Authority
WIPP	Waste Isolation Pilot Plant (United States)

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