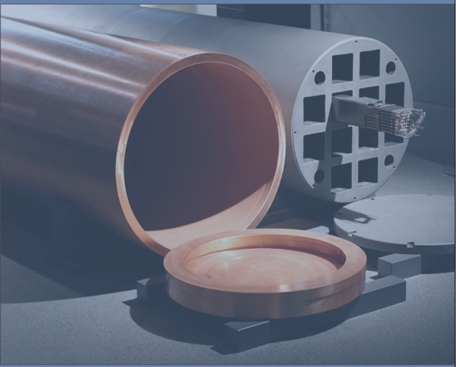

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel

Kommission
Lagerung hoch radioaktiver Abfallstoffe
K-MAT 51

Overview and Summary

Report to the United States Congress and the Secretary of Energy

November 2015

UNITED STATES
Nuclear Waste Technical Review Board

U.S. Nuclear Waste Technical Review Board

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel

Overview and Summary

Report to the United States Congress and the Secretary of Energy

November 2015

U.S. Nuclear Waste Technical Review Board

Note: Professor Sue Clark of Washington State University served as a Board member from July 28, 2011 to October 31, 2014. During that time, she played an instrumental role in developing this report. Allen Croff joined the Board in February, 2015, after the development of the report was well advanced.

U.S. Nuclear Waste Technical Review Board Staff

Executive Staff

Nigel Mote	*Executive Director*
Debra L. Dickson	*Director of Administration*

Senior Professional Staff

Robert E. Einziger	*Materials Science*
Bret W. Leslie	*Geoscience*
Daniel S. Metlay	*International, Social Science*
Daniel G. Ogg	*Nuclear Engineering, Operations*
Roberto T. Pabalan	*Geochemistry, Physical Chemistry*
Karyn D. Severson	*External Affairs*

Administrative & Support Staff

Davonya Barnes	*Information Systems Specialist*
Jayson S. Bright	*Systems Administrator*
Linda J. Coultry	*Program Support Specialist*

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

November 2015

The Honorable Paul Ryan
Speaker
United States House of Representatives
Washington, DC 20515

The Honorable Orrin G. Hatch
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Ernest J. Moniz
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Ryan, Senator Hatch, and Secretary Moniz:

The U.S. Nuclear Waste Technical Review Board was created by Congress in the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (Public Law 100-203) to evaluate the technical and scientific validity of activities undertaken by the Secretary of Energy to implement the Nuclear Waste Policy Act of 1982. In accordance with provisions of the NWPAA directing the Board to report its findings, conclusions, and recommendations to Congress and the Secretary, the Board submits two reports:

- *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Overview and Summary*
- *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis*

The Board's objective in writing both documents is to provide policymakers with information about efforts in the United States and other countries to site a deep-mined, geologic repository for high-level radioactive waste (HLW) and spent nuclear fuel (SNF). The reports rely on a comparative historical inquiry into two dozen siting efforts that have taken place over the past half century in ten different nations. The *Overview and Summary* is a short synopsis of the major insights that derive from that study. The *Detailed Analysis* is an in-depth account that provides the empirical foundation for those conclusions.

In keeping with the Board's technical mandate, the Board takes no position on whether a new effort should or will be undertaken to site either the country's first or second repository; that

Telephone: 703–235–4473 Fax: 703–235–4495 www.nwtrb.gov

decision will be made by policymakers. The two documents do include four recommendations related to technical practices that should be adopted *if* policymakers decide to restart a site-selection process for a deep-mined geologic repository in the United States. In particular, the recommendations address the preparation of site-suitability criteria to replace the Department of Energy's (DOE's) 1984 *Siting Guidelines* and the timing of when a state might object to the President's nomination of a repository site.

> *The Board recommends that DOE's 1984* Siting Guidelines *be adopted as a sound basis for developing any new rules that might structure a future siting process. A site-suitability regulation that relies on a technically complex performance assessment, such as DOE's 2001 regulation for Yucca Mountain, does not provide a sound basis for the initial stages of site selection.*
>
> *The Board recommends that the 1984* Siting Guidelines *be supplemented with Host-Rock-Specific Criteria that are applicable to the geology-specific concepts (including relevant engineered barriers) that have been advanced for disposing of HLW and SNF in salt, crystalline rock, or clay/shale formations and their associated environmental settings.*
>
> *The Board recommends that, to the greatest extent possible, the development of any new site-suitability criteria minimize the ambiguity that facilitates the implementer's discretion in applying them, helping ensure the objectivity of the process and public confidence in its outcome. If, at any point during the siting process, the criteria need to be changed, the implementer should use a transparent and meaningfully participatory process to do so.*
>
> *The Board recommends that any new siting process preserve the requirement in the 1982 Nuclear Waste Policy Act that a final choice of site await extensive underground characterization.*

The Board hopes that Congress and the Secretary will find the information in the two documents to be useful. The Board looks forward to continuing its ongoing technical and scientific evaluation of DOE activities related to disposing of spent nuclear fuel and high-level radioactive waste.

Sincerely,

Rodney C. Ewing
Chairman

Contents

Figures, Boxes, and Tables

Acknowledgments

In preparing this report, the Board has benefited from conversations with implementers, regulators, technical overseers, interested and affected parties, and scholars in Belgium, Canada, China, Finland, France, Germany, Japan, Sweden, Switzerland, the United Kingdom, and the United States. The Board greatly appreciates all the information and insights that those individuals have provided.

The preparation of this report also has benefited from the assistance of the Department of Energy's Office of Legacy Management. That office has been able to retrieve electronic copies of key documents related to the history of the radioactive waste management program in the United States. The Board greatly appreciates that support.

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

The United States is in the midst of a debate of how to manage for the long term the ever-growing stocks of spent nuclear fuel (SNF) and high-level radioactive waste (HLW) produced at commercial power plants and at the nuclear weapons complex. The fate of the congressionally approved site at Yucca Mountain for the nation's first deep-mined, geologic repository dedicated for those wastes is now in limbo. The Obama Administration's policy is to find a new site through a consent-based process. In fact, the Administration is proposing to develop two repositories, one to dispose of defense HLW (and perhaps some defense SNF) and another for the remainder of the inventory. All the while, supporters of the Yucca Mountain project are working to revive it.

If policymakers decide to launch a new repository-siting effort, an understanding of previous repository-siting efforts, both in the United States and abroad, might help to inform decisions defining and implementing the siting process. For this reason and to apprise the public of a critical issue associated with the long-term management of HLW and SNF, the U.S. Nuclear Waste Technical Review Board has written this report.

Every country that has chosen a strategy for managing its HLW and SNF over the long term has opted for disposal in deep-mined, geologic repositories. Depending on the available rock types, a nation may be able to adopt one or more disposal concepts—designs for a repository system composed of the host-rock formation and engineered barriers—to isolate the HLW and SNF from the accessible environment.

This document presents a historical analysis of 24 instances in ten countries in which implementers, such as the U.S. Department of Energy (DOE), attempted to find a repository site. Six national programs remain on track. The one in the United States is not among them. In Finland, France, and Sweden, the implementers are moving beyond the selection of a site by seeking or preparing to seek approval from their regulatory authorities to construct a facility.

This document rests on the premise that finding a repository site is a difficult *socio-technical challenge*. Many levels of government exercise power; affected constituencies strive to make their voices heard, often with the goal in mind of preventing the development of a repository; sharp disagreements over values and how they are traded off arise; the science and engineering involved is complex and specialized, and the resulting uncertainties may be difficult, if not impossible, to resolve.

This report also rests on the premise that finding a repository site requires the metaphorical passage, generally more than once, of possible locations through two filters, a Technical Suitability Filter and a Social Acceptability Filter. The Technical Suitability Filter winnows sites based on factors most related to the physical characteristics of the locations. The Social Acceptability Filter winnows sites based not only on choices made by the political estate but also on actions taken by various interested and affected nongovernmental parties.

This report describes how the Technical Suitability Filter is established, typically by implementers through formal rules or regulations collectively termed "site-suitability criteria." *Exclusion Criteria* are used by the implementer to eliminate sites at the very beginning of the siting process. The implementer also provides these criteria to communities that might be interested in exploring the possibility of hosting a repository. Knowing that certain geologic characteristics almost automatically preclude the development of such a facility, communities can avoid spending time and resources unnecessarily. *Host-Rock-Specific Criteria* are disposal-concept specific and identify rock properties that would indicate that a repository developed in a particular formation would perform satisfactorily. *Generic Criteria* are used to compare sites in completely different geologic environments. The type of criteria used by the implementer can strongly influence how it winnows down *prospective settings* to *potential sites* to *candidate sites*. Consequently, how interested and affected parties perceive and understand the implementer's actions also may be affected by the type of site-suitablity criteria.

The Social Acceptability Filter can take many forms, including legislative determinations, referenda, mass action, and negotiated agreements. Passage through it can result in a range of outcomes, including selection of a repository site, interested and affected parties taking a wait-and-see stance, or protests based on poor technical analyses or flawed procedures. Increasingly, nations have created consent-based siting processes. These also take a variety of forms, depending on who consents, how consent is granted, and at what point consent can be withdrawn. Consent-based processes have resulted in the selection of a site in some countries; in others, such processes have not achieved their desired end.

Although passage through one filter can mostly be described and understood independently of passage through the other, in several respects the two are interdependent. Examples of this interdependence include the following: simplicity of the disposal concept and social acceptability; the order in which a possible site passes through the filters; political influences in determining site-suitability criteria; technical ambiguity, bureaucratic discretion, and social trust; support or opposition to nuclear energy production and attitudes toward radioactive waste management**;** and technical uncertainty and informed consent.

As this report details, experience siting a deep-mined, geologic repository has been mixed. Notwithstanding this history, the Board strongly agrees with the international consensus within the scientific and engineering communities and among implementers and regulators that developing such a facility is technically feasible and provides a compelling level and duration of protection.

Thus, the Board advises DOE that it should not pursue any disposal strategy that might distract from focused efforts to develop a deep-mined, geologic repository.

Based on the information developed in this report, and in keeping with its technical mandate, the Board presents four recommendations that policymakers should consider if they decide to launch a new siting process. These recommendations address the preparation of site-suitability criteria to replace DOE's 1984 *Siting Guidelines* and the timing of when a state might object to the President's nomination of a repository site. The basis for the recommendations is outlined in this report. A more extensive discussion can be found in the companion volume, *Detailed Analysis*, released at the same time as this report.

1. Because of the geological diversity in the United States, it may not be possible to choose a single disposal concept in advance of the site-selection process. (The Finns and the Swedes were able to do so because a single rock type, crystalline rock, underlies virtually all of both countries.) Consequently, despite their limitations, Generic Criteria will have to provide the initial foundation for any new set of site-suitability criteria. DOE's 1984 *Siting Guidelines,* a striking example of Generic Criteria, is consistent with international practice and is technically defensible. A different approach, embodied in DOE's 2001 Yucca Mountain-specific site-suitability regulation, relies on probabilistic performance assessment. Putting aside the ongoing debate over the utility and validity of that methodology, using it to winnow down sites is inappropriate and technically questionable. The data needed to employ sensibly such an approach simply are not available at the earliest stages of any siting effort.

   Therefore, the Board recommends that DOE's 1984* Siting Guidelines *be adopted as a sound basis for developing any new rules that might structure a future siting process. A site-suitability regulation that relies on a technically complex performance assessment, such as DOE's 2001 regulation for Yucca Mountain, does not provide a sound basis for the initial stages of site selection.

2. DOE applied the 1984 *Siting Guidelines* to compare locations when it reduced the number of prospective settings for the second repository. In that case, all the sites were in crystalline rock formations. Using Generic Criteria when Host-Rock-Specific Criteria would have sufficed unnecessarily complicated matters. The development of new guidelines should anticipate this situation. Adding Host-Rock-Specific Criteria that are disposal-concept specific would simplify and make more transparent the technical basis for DOE's decisions in the future.

   Therefore, the Board recommends that the 1984* Siting Guidelines *be supplemented with Host-Rock-Specific Criteria that are applicable to the geology-specific concepts (including relevant engineered barriers) that have been advanced for disposing of HLW and SNF in salt, crystalline rock, or clay/shale formations and their associated environmental settings.

3. DOE also used the 1984 *Siting Guidelines* to winnow the five potential sites for the first repository down to three candidate sites. DOE exercised its legitimate discretion to interpret ambiguous language in the rule and to determine how its multiattribute utility analysis methodology should be carried out to distinguish among sites. In both

that case and the down-selection of prospective settings for the second repository, charges of unfairness were leveled that could not be dispelled neatly and persuasively. There is a fine line between protecting the discretion required for bureaucratic flexibility and enlarging the domain of discretion to the point that bureaucratic decisions appear unaccountable. If new (or revised) guidelines are written, they must be scrutinized carefully to ascertain on which side of that line they fall. Erring on the side of reducing discretion is a conservative approach but one that is more likely to be viable in the long term.

Therefore, the Board recommends that, to the greatest extent possible, the development of any new site-suitability criteria minimize the ambiguity that facilitates the implementer's discretion in applying them, helping ensure the objectivity of the process and public confidence in its outcome. If, at any point during the siting process, the criteria need to be changed, the implementer should use a transparent and meaningfully participatory process to do so.

4. As investigations related to siting proceed at the surface as well as in laboratories, knowledge is gained about the potential performance of a proposed repository system. That knowledge is usually supplemented with the construction of underground research laboratories in the same hydrogeologic environment as the candidate site. Thus, the chances of scientific and technical surprises arising are reduced even if they cannot be completely eliminated. Communities asked to consent to the choice of site generally are concerned about when a right of withdrawal can be exercised because disagreements between the implementer and the community may arise over whether any surprises encountered can be worked around or whether they automatically disqualify a site. The 1982 Nuclear Waste Policy Act uniquely requires that investigations at depth be completed before a final decision on selecting a repository site can be made. The implementer *and* the affected community/state both benefit from investigations carried out at depth where the repository will be built. Resources might not be expended in vain. Giving consent or withholding it until the time of "full disclosure" permits a more informed choice.

   Therefore, the Board recommends that any new siting process preserve the requirement in the 1982 Nuclear Waste Policy Act that a final choice of site await extensive underground characterization.

Introduction

Seventy years into the nuclear enterprise, no nation has put into place the means for managing over the very long term the toxic by-products of that activity: high-level radioactive waste (HLW) and spent nuclear fuel (SNF). As a consequence, responsibility for controlling those materials on a *temporary* basis has been handed down from one generation to the next and then again to the next and then again to the next, with the hope always being that one cohort would find a way out of the tangle that its predecessors had never discovered.

Every country that has evaluated different strategies for the long-term management of HLW and SNF has selected disposal in a deep-mined, geologic repository as the preferred policy. Indeed, broad agreement exists internationally within the scientific and technical communities and among those charged with developing, regulating, and approving a repository that the disposal of HLW and SNF in such a facility is technically feasible and provides a compelling level and duration of protection. Box 1 provides the legal definitions of HLW and SNF.

> **High-level radioactive waste** is defined as "the highly radioactive material resulting from the reprocessing of spent nuclear fuel, including liquid waste produced directly in reprocessing and any solid material derived from such liquid waste that contains fission products in sufficient concentrations; and other highly radioactive material that the Nuclear Regulatory Commission, consistent with existing law, determines by rule requires permanent isolation."
>
> **Spent nuclear fuel** is defined as "fuel that has been withdrawn from a nuclear reactor following irradiation, the constituent elements of which have not been separated by reprocessing."
>
> *Nuclear Waste Policy Act (42 U.S.C. 10101), Section 2, Paragraphs 12 and 23.*

Box 1. Definitions of high-level radioactive waste and spent nuclear fuel

In 1987, Congress established the Nuclear Waste Technical Review Board (Board or NWTRB). Its mandate is to evaluate the technical and scientific validity of subsequent actions taken by the Secretary of Energy to implement the Nuclear Waste Policy Act. The Board has written this report to apprise policymakers and the public about one crucial, but problematic, element common to all national nuclear waste-management programs: selecting a site for the repository.

It is no secret that this country is in the midst of a repository-siting debate. In 2002, Congress passed legislation accepting President George W. Bush's recommendation that a site at Yucca Mountain in Nevada be chosen for the nation's first deep-mined, geologic repository for HLW and SNF. Although the Department of Energy (DOE) submitted a license application to the Nuclear Regulatory Commission (NRC) in 2008 to construct this facility, the project is now in limbo. The Obama Administration determined in 2010 that a new siting effort should be initiated. At the direction of the President, DOE appointed the Blue Ribbon Commission on America's Nuclear Future (BRC) to review policies for managing the back end of the nuclear fuel cycle. Among its recommendations, the BRC called for the development of a consent-based process for siting nuclear waste-management facilities (BRC 2012). Further, based on analyses prepared by DOE, the President signed a memorandum in 2015 concluding that, under the Nuclear Waste Policy Act, the "development of a repository for the disposal of high-level radioactive waste resulting from atomic energy defense activities only [was] required" (Obama 2015).

As a technical body, the Board takes no position in these repository-siting debates. But if policymakers should determine that new site-selection efforts need to be launched, for either a first or second repository, this report can help identify the set of issues that might be considered as well as a range of alternatives that might be assessed.

This report strives to make *comparisons* of siting efforts across nations and among siting efforts within a single nation. Consequently, it does not tell each country's story in one place, for example, in separate chapters or sections. Rather, it examines a given activity—such as screening as many as 200 locations to identify five or six that might be technically suitable—and details how that activity was carried out in various nations. By learning how different countries tackled the same task, the reader may gain some understanding about the range of possibilities that present themselves and about their efficacy.

The report begins with a discussion of siting as a process and the framework that will be used to structure the historical record. A brief description of strategies for the disposition of HLW and SNF—disposal concepts—that have been the subject of considerable scientific attention follows. The concepts envision a repository system composed of both natural and engineered barriers. Such a system would be constructed deep underground using conventional mining techniques. The report then turns to an analysis of how those responsible (mainly *implementers like DOE*) evaluate the technical suitability of possible sites, sometimes more than once. It then considers how implementers, the political estate, and interested and affected parties determine whether a site is socially acceptable. Although these two activities are largely independent, they sometimes interact. The report therefore explores the nature of those interdependencies.

If policymakers do decide to launch a new search for a repository, many issues will have to be addressed beyond the development of procedures for determining where the facility might be located. What kind of implementing organization would carry out such activities? How would that organization be financed? How should the interactions between the implementer and interested and affected parties be structured? These are critically important questions, but this report focuses solely on how the location of a repository might be selected. Moreover, consistent with its legislative charter, the Board advances only recommendations related to the *technical aspects* of siting a repository.

Thinking About Siting

Siting a deep-mined, geologic repository is an archetypical example of what social scientists call a messy problem. Such problems possess these features (see, for example, Ackoff 1974):

- Numerous parties are involved;
- Scientific uncertainties abound that may not be fully resolvable, even in principle;
- Sharp conflicts persist over what values are important and what trade-offs should be made; and
- Decision-making processes are often ill-defined, ever changing, and opaque.

Not surprisingly, then, the historical record clearly demonstrates that siting a repository is a demanding and challenging activity. *In virtually every country considered in this report, the siting process broke down at least once and had to be reconstituted.*

Siting begins when an implementer decides to find a specific location suitable for developing a deep-mined, geologic repository. It ends when the implementer has explicitly chosen that location and when that choice has been ratified either by a branch of the central government (typically the legislature) or by a subordinate unit of government, such as a municipality or a Native American tribe. It can also end if that choice is not ratified.

For implementers, the goal of any site-selection undertaking is winnowing down a large number of possible locations to find a smaller number, sometimes only one, that are both technically suitable *and* socially acceptable. This process is prescribed in national laws and regulations. It is typically designed to be phased and iterative, moving from one stage to the next. The implementers generally address the technical and the social aspects in parallel. However, the laws and regulations that govern the process create separate decision points for each stage. At those milestones, the implementer and the political estate make specific *determinations* either of suitability or acceptability. In

In each of the ten countries that sought to choose a site for a repository, the process has required decades of detailed technical investigations and engagement with communities. Although missteps have occurred in virtually all of those nations, four of them have chosen repository sites.

each of the ten countries that have attempted to choose a site for a deep-mined, geologic repository, the process has required decades of detailed technical investigations and engagement with communities. Although missteps have occurred in virtually all of those nations, four of them—Finland, France, Sweden, and the United States—have chosen repository sites.

Any attempt to represent the siting process using a diagram or schematic almost always will fail to capture some element of its messiness. But perhaps Figure 1 provides a good compromise. The light and dark blue areas depict sets of sites that are technically suitable at early and late stages of the siting process, respectively, and the light and dark red areas portray sets of sites that are socially acceptable at each of those two stages. Waste-management programs need to find sites that belong to both the blue and red sets. At the early stage, many locations, *prospective settings*, remain in contention either because available information is insufficient to eliminate them or because, at that point in the process, the requirements for suitability and acceptability are looser. At the late stage, fewer locations, *potential sites*, remain in contention either because available information eliminates many others or because the requirements for suitability and acceptability have become more stringent. Ultimately, a handful of locations, *candidate sites* (not shown in Figure 1), emerge from the winnowing process.

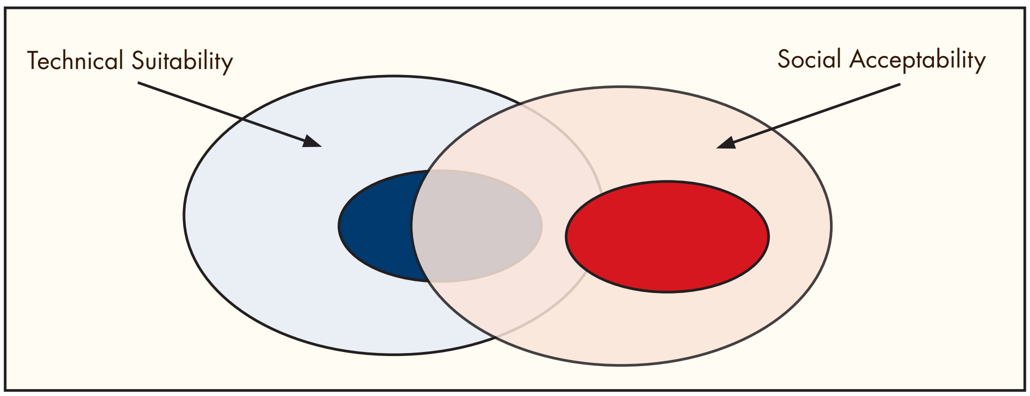

Figure 1. Selecting a site is an iterative process. It involves successive evaluations of technical suitability and social acceptability. Lighter shades denote early-stage judgments, and darker shades denote late-stage judgments.

This figure has been intentionally drawn to show no overlap at the late stage because, as is often the case, no site is both technically suitable *and* socially acceptable. Faced with this outcome, the implementer has to choose between at least two fundamentally different courses of action. It can suspend the site-selection process to obtain additional information, or work on the social aspects in the hope that improved or evolving knowledge about suitability and/or changes in attitudes toward acceptability would permit the selection of a site. If that hope is not realized, however, the implementer may be forced to launch an entirely new site-selection process. In Canada, France, Germany, Japan, Sweden, Switzerland, the United Kingdom, and the United States, the implementer did precisely that. Alternatively, the implementer could explicitly or implicitly decide to alter the technical suitability and social acceptability requirements (or both) so that locations that had been (or might have been) rejected are now deemed satisfactory. In the United States, DOE revised the assumptions about the likelihood associated with human intrusion at the Waste Isolation Pilot Plant (WIPP) in New Mexico. Also, DOE changed the regulation regarding the suitability of the Yucca Mountain site.

Because messiness is an intrinsic property of a site-selection process, attempts to describe and analyze the historical record must necessarily rely on complex arguments and logic. Implementers have to juggle many balls, organizing a myriad of scientific and engineering studies, and managing a dynamic and potentially hostile social environment. To capture and make useful this historical record, some simplification cannot be avoided. This report adopts the interpretation of the siting process depicted in Figure 2.

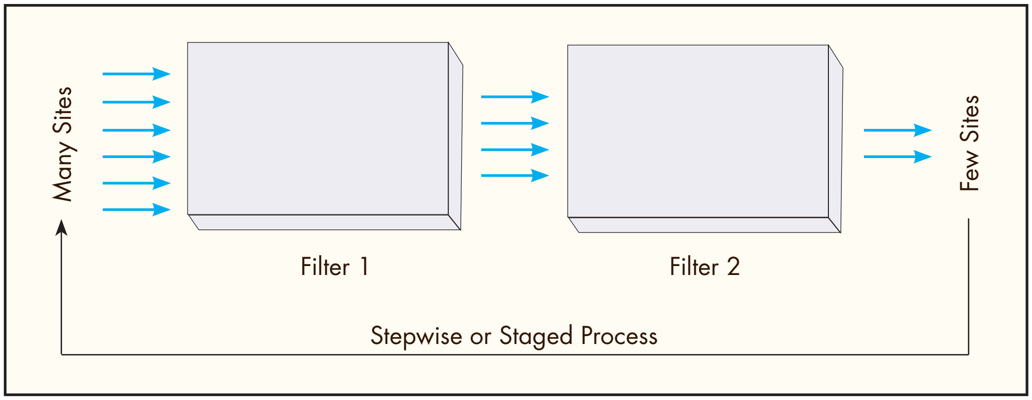

Figure 2. A simplified interpretation of the siting process. Possible locations must pass through both a Technical Suitability Filter and a Social Acceptability Filter to be selected as a site for a deep-mined, geologic repository.

At each stage of the siting process, when implementers, the political estate, and interested and affected parties must make the specific legal and regulatory determinations, sites are metaphorically filtered so that some "pass through" and others do not. Like those determinations, passage through one filter is *temporally separated* from passage through the other. To remain in contention, proposed sites will need to travel through both Technical Suitability *and* Social Acceptability Filters, often more than once. The order in which they do so varies from nation to nation. (Indeed, sometimes the order shifts as the process moves from one stage to the next.) But, again, what is unavoidable is the necessity to ultimately pass the proposed sites through both.

When countries began to search for repository sites in the late 1960s and early 1970s, the prevailing view was that passage through the Technical Suitability Filter would be more challenging than passage through the Social Acceptability one. Experience gained since then has suggested that passage through the Social Acceptability Filter is as challenging, if not more so, as passage through the Technical Suitability Filter. Recognition of this reality has led implementers in many countries to alter fundamentally the processes they use for selecting repository sites.

Experience over the past 40 years suggests that passage through the Social Acceptability Filter is at least as challenging as passage through the Technical Suitability Filter.

Approach

This report provides a traditional historical analysis that is aimed at "reconstructing" how siting processes have unfolded over time. To do so, it examines two dozen cases in the United States and abroad where implementers of national waste-management programs sought to identify locations for hosting either a deep-mined, geologic repository or an underground research laboratory (URL) that would pave the way for a repository. These 24 cases and their outcomes are listed in Table 1 on the following page. With the exception of the siting of WIPP in southeast New Mexico, all of the cases involve choosing a location for a repository in which HLW and SNF would eventually be disposed. (WIPP accepts only transuranic radioactive waste from the nuclear defense complex.) Notwithstanding that difference, WIPP is included because the process through which it was sited offers important insights and lessons.

The report relies on several different types of evidence, including official publications; internal memoranda and evaluations prepared by the implementer; secondary sources, especially peer-reviewed scholarship; and interviews with key participants. Every effort was made to reconcile the conclusions and inferences drawn from multiple sources. Social scientists especially understand, however, the difficulties of reconstructing historical events, particularly when heavy reliance must be placed on official public records. Those documents may not always be available. Even if they are, they may not describe events and judgments candidly. Alternative narratives, including those where the motivations of those involved may be more mixed and complicated than what was manifested, often cannot be conclusively dismissed.

Experience	Outcome
Canada	
The Adaptive Phased Management program seeks volunteer communities interested in learning more about hosting a deep-mined, geologic repository (2006-present).	Ongoing
China	
Site selection for an underground research laboratory in granite (1989-present).	Ongoing
Finland	
Site selection for a deep-mined, geologic repository in granite in a volunteer community (1982-1999).	Repository site in the community of Eurajoki was selected.
France	
Site investigations by the French Atomic Energy Commission to determine the technical suitability of sites in four different host rocks (1987-1990).	Terminated because of public and political opposition
Site selection for an underground research laboratory in granite and clay in a volunteer community (1993-2006).	Repository site in the Meuse/Haute-Marne *département* was selected.
The Granite Mission sought to find a volunteer community willing to host an underground research laboratory (1999-2001).	Terminated because of public and political opposition
Germany	
The Federal Ministry of Research and Technology's Institute for Soil Research sought a potential repository site in salt (1963-1967).	Terminated because of public and political opposition
The Federal Ministry of Research and Technology asked the Nuclear Fuel Reprocessing Company to identify sites for a nuclear complex that would have included a deep-mined, geologic repository (1973-1976).	Terminated because of public and political opposition
The Government of Lower Saxony selected a site for a deep-mined, geologic repository in salt (1976-present).	Work at the Gorleben site was suspended because of public and political opposition.
The AkEnd Commission proposed site-suitability criteria applicable to a variety of host rocks and proposed a siting process (1999-2002).	Terminated because of public and political opposition

Table 1. Siting experiences detailed in this report

Experience	Outcome
Japan	
Site-selection process sought volunteer communities interested in learning more about hosting a deep-mined, geologic repository (2002-2014).	The approach adopted in 2002 did not succeed in eliciting a volunteer site. That approach is to be replaced by a still-undefined strategy.
Sweden	
Site investigations for a deep-mined, geologic repository in granite (1977-1988).	Terminated because of public and political opposition
Site investigations for a deep-mined, geologic repository in granite in a volunteer community (1992-2009).	Repository site in the community of Östhammar was selected.
Switzerland	
Project Gewähr attempted to identify a site in granite for a deep-mined, geologic repository (1978-2004).	Terminated because of the difficulty in identifying a site where the concept could be technically implemented.
The Swiss Government launched the Sectoral Plan aimed at finding a site for a deep-mined, geologic repository in Opalinus clay (2008-present).	Ongoing
United Kingdom	
Managing Radioactive Waste Safely program sought volunteer communities interested in hosting a deep-mined, geologic repository (2008-2013).	Terminated because the Cumbria County Council voted to withdraw from the process

Table 1. Siting experiences detailed in this report (continued)

Experience	Outcome
United States	
The Atomic Energy Commission sought to identify a technically suitable site in salt for a deep-mined, geologic repository (1958-1971).	Decision to develop a demonstration repository in central Kansas was reversed for technical and political reasons.
The Atomic Energy Commission (1972-1974), Energy Research and Development Administration (1975-1977), and DOE (1977-1982) sought to identify a technically suitable site for a deep-mined, geologic repository in three different host rocks.	Terminated because of public opposition
As mandated in the Nuclear Waste Policy Act, DOE identified nine potentially acceptable sites for a deep-mined, geologic repository in three different host rocks (1983).	Sites in six states were identified.
As mandated by the Nuclear Waste Policy Act, DOE nominated five sites for possible characterization of their technical suitability for a deep-mined, geologic repository (1984).	Sites in five states were identified.
As mandated by the Nuclear Waste Policy Act, DOE recommended and President Ronald Reagan selected three sites for characterization to determine their technical suitability for a deep-mined, geologic repository (1985-1987).	Sites in Nevada, Texas, and Washington were identified.
With the passage of the Nuclear Waste Policy Amendments Act in 1987, site characterization was limited to Yucca Mountain, Nevada. In 2002, Congress approved the selection of that site for development as a repository.	Development of the Yucca Mountain site as a deep-mined, geologic repository is in limbo.
As mandated by the Nuclear Waste Policy Act, DOE sought to identify sites in granite for the second deep-mined, geologic repository (1983-1986).	Potential sites in 17 states were proposed. Project was terminated because a second repository was "not needed."
DOE selected a site in southeast New Mexico for the Waste Isolation Pilot Plant (WIPP), a deep-mined, geologic repository for transuranic-contaminated radioactive waste (1977-1992).	In 1998, the Environmental Protection Agency (EPA) certified that WIPP complied with all applicable federal waste disposal regulations.

Table 1. Siting experiences detailed in this report (continued)

Repository Systems and Disposal Concepts

A shared vision about deep-mined, geologic repositories has emerged in the more than half century since a panel convened by the U.S. National Academy of Sciences first advanced the idea. The facility would be located 300 to 1,000 meters beneath the surface in a stable host-rock formation and would be constructed using conventional mining techniques. The repository system would have both natural components—the host rock and tunnels (drifts) where the waste would be emplaced—and engineered components—the waste form, waste package, and drift seals. Both components would contribute to the isolation and containment of the HLW and SNF, although performance would be allocated among the barriers differently, largely depending on the particular host rock selected. Figure 3 presents what a generic repository might look like.

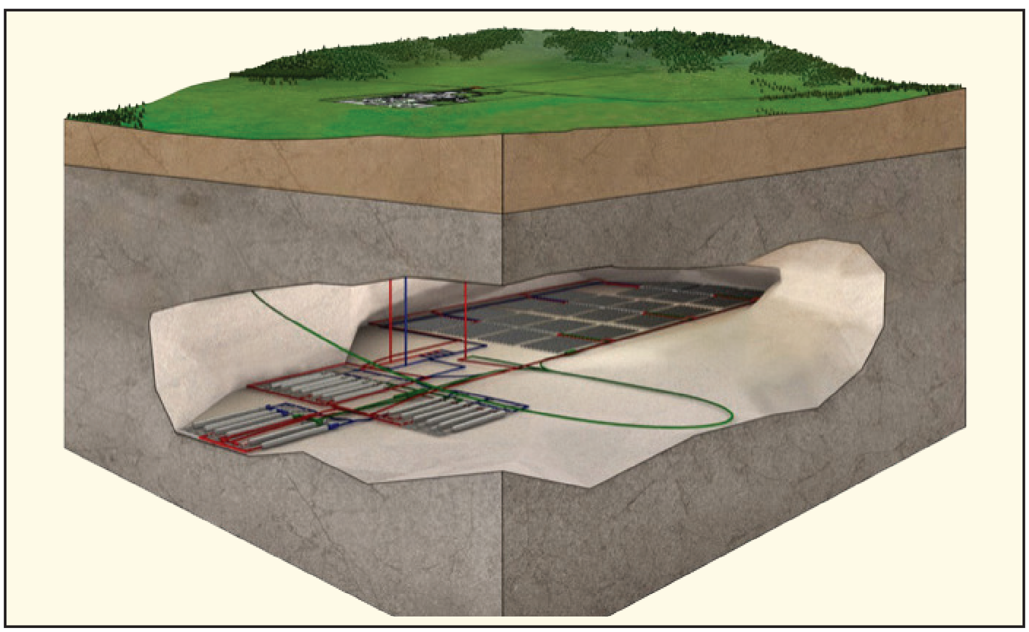

Figure 3. Layout of a generic deep-mined, geologic repository. The black lines represent drifts where the waste will be emplaced; the green, blue, and red lines are shafts and ramps. (Source: Nuclear-News Net 2013)

The implementer's objective in selecting a site and designing the facility is to delay and then limit the release of radionuclides in HLW and SNF that can reach the accessible environment, primarily through transport by groundwater. Over the years, mature *disposal concepts* optimized for different geologic formations found in each country have been crafted. (See Box 2 for more information about disposal concepts.)

The basic requirement for any repository system is its ability to contain and retard the movement of radionuclides sufficiently so that socially acceptable risk levels specified in national regulations are met. Most **disposal concepts** for designing the repository system rely on a set of independent and often redundant barriers—both natural and engineered—to restrict the dissolution and movement of radionuclides and thereby provide a high degree of assurance that exposures will remain at these acceptably low levels.

The geologic formation is the most important natural barrier in a disposal concept. The rock's properties may prevent radionuclides from moving either physically or by chemically bonding with the radionuclides (sorption). The formation's hydrogeologic properties, which control storage and rates of flow of underground water through pores and fractures, and its geochemistry, the elemental composition and oxidation state of minerals in the rocks and of solutes in the underground water, can also limit radionuclide concentrations by reducing their solubility or mobility.

Engineered barriers to limit the release of radionuclides to the geologic formation generally include one or more of the following: (1) the waste form itself, (2) containers into which the waste is encapsulated, and (3) special radionuclide- and groundwater-retarding material placed around the waste containers and in the drifts, commonly referred to as backfill.

Today, the most mature disposal concepts have been developed for a repository system constructed in salt, crystalline rock, clay/shale, or volcanic tuff formations.

Box 2. Disposal concepts for designing repository systems

In some countries, such as Sweden and Finland, the crystalline bedrock is the only viable host rock. In Belgium and Switzerland, a clay formation is the only practical alternative. In other countries, such as the United States, a diversity of rock types, including salt, crystalline rock, clay/shale, and volcanic tuff, are available for consideration. The disposal concepts associated with different host-rock geologies have been subjected to and have satisfied international peer reviews. Table 2 on the following page summarizes the key features of the four disposal concepts that have been investigated in the United States and elsewhere. The technical characteristics of each concept are discussed in greater detail in the companion volume.

Table 2 makes clear that the performance of a repository grounded in any of these disposal concepts depends not only on the properties of the host rock, but also on the capability of the engineered barriers, such as metal canisters, waste forms, buffers, and drip shields. This joint dependence complicates the site-selection process especially when locations in *different geologic formations* must be compared. If the implementer is ultimately concerned about the performance of the *entire repository system*, what sense does it make just to contrast the isolation and containment properties, for example, of a salt and a clay formation? As the companion volume to this report elaborates, DOE addressed this question by positing that, for the purposes of the down-selection of sites, the engineered barriers associated with all the concepts would have a constant, but minimal, level of performance.

Host Rock	Safety Properties Associated with the Host Rock and Natural Environment	Safety Concerns Associated with the Host Rock	Importance of Engineered Barriers	Countries Committed to the Concept	Countries That Are Actively Investigating the Concept
Salt	• Absence of flowing water • Self-healing fractures • High thermal conductivity to remove heat	• Heat induces moisture movement • Hydrogen gas buildup • Increased likelihood of human intrusion for natural resources • Corrosivity of any intruding water	• High at WIPP (magnesium oxide to protect against the consequences of human intrusion)		• Germany • United States
Crystalline rock	• Stable for mining • Provides compatible environment for engineered barriers • Low fracture density	• Corrosion of metal canister • Stability of bentonite buffer • Changes to the geohydrological and geochemical conditions	• High (e.g., copper canisters and bentonite clay)	• Finland • Sweden	• Canada • China • Japan • United Kingdom • United States
Clay/shale	• Self-sealing fractures • Diffusion-controlled radionuclide migration • High sorption capacity	• Potential for permeable faults • Increased likelihood of human intrusion for natural resources	• High (vitrified waste forms and/ or corrosion-resistant waste packages)	• Belgium • France • Switzerland	• Canada • China • Japan • United Kingdom • United States
Volcanic tuff at Yucca Mountain, Nevada	• Arid climate reduces the amount of water entering the repository drifts • Closed hydrologic basin limits the distance that radionuclides can travel	• Uncertainty about the presence of fast flow paths • Potential for deliquescence-induced corrosion of the waste package • Oxidizing conditions, which allow for mobilization of radionuclides • Heat-induced moisture movements	• High (corrosion-resistant waste packages and drip shields)	• United States (currently in political and legal limbo)	

Table 2. Characteristics of disposal concepts

Technical Suitability Filters

Implementers design Technical Suitability Filters to differentiate among and to compare sites. This filter typically defines a set of requirements—collectively termed "site-suitability criteria."

Starting in the 1960s, most national programs focused on a single disposal concept. Then the implementer evaluated sites using both *Exclusion Criteria*, which disqualified at the start certain locations, as well as *Host-Rock-Specific Criteria,* which were associated with the relevant disposal concept, to winnow broad areas, prospective settings, down to potential and candidate sites. These criteria include extensive fracturing, water chemistry, homogeneity, and sorptive capacity.

Spurred on by a fundamental paradigm shift that began in the mid-1970s, national waste-management programs recognized that it might be possible to pursue multiple disposal concepts. So in addition to Exclusion Criteria, *Generic Criteria* were crafted that would arguably portend a site's suitability. For instance, the site had to possess a "low hydraulic gradient" in and between the host rock and the immediately surrounding geohydrologic units or it had to have "good temperature compatibility." The implementer then applied Generic Criteria to screen and compare potential sites found in different host rocks.

More recently, national waste-management programs have employed Exclusion Criteria by themselves for another purpose: to inform communities possibly interested in hosting a repository about what factors would almost certainly disqualify a site.[1] If a community's real estate is promising, it can then engage with the implementer to determine, based on more extensive investigations, whether particular sites might be suitable for developing a repository. As the process moves forward, potential sites are evaluated against increasingly more detailed and exacting technical criteria.

Box 3 on the following page provides additional information about each of the three types of site-suitability criteria.

[1] The "permeability" of these Exclusion Criteria is likely attributable to two complementary rationales: not wanting to narrow prematurely the pool of volunteers and not wanting to create the perception that a particular candidate site has been selected prematurely.

Implementers in the United States and abroad have collectively created three types of site-suitability criteria, that is, sets of requirements used to determine whether a particular location might be developed as a deep-mined, geologic repository. What distinguishes the types is that they are crafted to serve different purposes.

Exclusion Criteria are applied to eliminate sites whose geologic (and sometimes logistical, operational, and social) characteristics almost automatically preclude the development of a repository. For example, implementers can use Exclusion Criteria to reject locations that may be too close to extractable resources, that may lie in tectonically unstable zones, or that may be situated beside active volcanos. In nations where volunteerism is a hallmark of the siting process, implementers also use Exclusion Criteria to provide guidance to communities that might be interested in exploring the possibility of hosting a deep-mined, geologic repository. By evaluating locations against the Exclusion Criteria early on in the siting process, the implementer minimizes the continuing demands placed on communities that might wish to volunteer but do not have control over an acceptable site.

Host-Rock-Specific Criteria are used when the implementer seeks to identify sites where only one type of geologic setting is available and, therefore, where only one disposal concept might be realized. Because these site-suitability criteria are concept specific, it is possible to include quantitative rock properties that would indicate how well a repository developed at a particular location might perform. For example, the earliest work to find a possible repository site in a salt formation in Germany required that it be 400-500 meters thick, that the top of the formation be at least 300 meters below ground, and that the formation have a surface area of at least six square kilometers. Those same German criteria also included attributes that were not associated with specific quantitative ranges or limits, such a "homogeneous rock salt" and "low permeability of overburden." But, because only one concept was involved, the validity of comparing sites using those more qualitative criteria was relatively straightforward and not likely to be contested.

Generic Criteria are employed when the implementer has the option of adopting more than one disposal concept and must compare sites in different geologic environments. Because these criteria must be applied to more than one type of host rock, they typically are generic in nature, thereby making it extremely difficult (although not impossible) to quantify the values for the various rock properties. For example, in the United States, the first site-suitability criteria set was largely generic and included language such as "low hydraulic gradient," "good temperature compatibility," and "the host rock and surrounding units shall be capable of accommodating thermal, chemical, mechanical, and radiation stresses." How those criteria would be compared across geologic settings presents significant methodological and empirical challenges.

Box 3. Three types of site-suitability criteria

How do implementers apply these site-suitability criteria? First, they determine whether a location should be rejected at the start. Depending on the disposal concept under consideration, only a few properties of the host rock can disqualify a site. The disposal concept employed by the Swedes to develop a repository in crystalline rock is based on the chemistry and the slow movement of groundwater. The disposal concept used in France and Switzerland to develop a facility in clay requires significant tectonic stability, that is, the lack of potential for active faulting or folding.

Table 3 records the Exclusion Criteria that have been explicitly adopted by several countries discussed in this report. Tectonic activity is the only circumstance that leads implementers in all these nations to reject a site. Fast groundwater flow, significant faulting, and the presence of natural resources in the proximity of a possible site, however, can raise significant questions about the viability of a particular location. But regardless of how Technical Suitability Filters are designed, they seem to eliminate relatively few prospec-

Condition	Canada	France	Japan	Sweden	Switzerland	United States*	United Kingdom
Fast and/or significant groundwater flow	■	■		■		■	
Unfavorable groundwater chemistry				■			
Tectonic activity	■	■	■	■	■	■	■
Inadequate depth and/ or extent of the host-rock formation					■	■	
Significant faulting in the host rock	■	■	■				■
Presence of natural resources	■		■			■	■
Volcanic activity			■				

*Prior to 2002. Red cells indicate that a site possessing the condition must by rule be excluded from consideration.

Table 3. Exclusion Criteria that disqualify a site for development as a deep-mined, geologic repository

tive settings from consideration at the start. For example, in Canada, of the 22 communities that expressed interest in exploring the possibility of hosting a repository, 21 passed the initial suitability test. In Finland, more than 100 locations passed through the initial Technical Suitability Filter. In most countries, potential repository sites can be found in many locations.

In most countries, potential repository sites can be found in many locations.

Second, although technical suitability is the *sine qua non* for the choice of any repository site, all the possible locations are not equally suitable, whether in terms of performance margins or confidence levels. Consequently, there are often calls from interested and affected parties for finding the "optimal" site. Yet the workability of seeking ever-better sites is quite problematic. So almost by default, national waste-management programs either explicitly or implicitly have limited their quest to the set of sites that is likely to comply with *threshold* safety and environmental protection regulations.

This objective strongly influences how the criteria for the filters are defined and presented. In some countries, such as Sweden, formal site-suitability criteria are not specified in advance. Host-Rock-Specific Criteria might informally guide the implementer's search. But the implementer typically preserves its discretion by declining to articulate the weight given to each, how trade-offs among them are handled, or how their contributions to performance are aggregated.

Even in those countries where formal site-suitability criteria have been established, preserving the implementer's discretion and accommodating the variability of the geology affect what language is approved to represent the benchmarks. Vague terms are typically adopted, which can be interpreted in a number of (possibly conflicting) ways. By controlling the definition and application of site-suitability criteria, implementers maintain some degree of flexibility in deciding which locations stay on the table and which are taken off.

Implementers design site-suitability criteria in ways that do not constrain their discretion when applying them.

This flexibility was present in the United States, where DOE twice applied its site-suitability regulation, the so-called *Siting Guidelines* (DOE 1984), which is a clear example of requirements that rely on Generic Criteria. In 1985, DOE developed an elaborate methodology to select potential sites in crystalline rock for the second repository that was mandated in the Nuclear Waste Policy Act. At the core of the approach was a geographic information system that mapped the 235 prospective settings onto a system of 500,000 one-mile-square grid cells. Each cell was evaluated by assigning a score (one to five) to five disqualifying conditions (Exclusion Criteria) and 20 additional factors. The overall favorability was determined by calculating the arithmetic mean of all the variables. Two workshops were convened to assign weights to each of the variables. The first was attended only by DOE team members; the second included state, but not tribal, representatives. The nine sets of variable weights thus generated allowed DOE to produce maps showing the aggregate favorability of each prospective setting. This seemingly systematic process was not without its critics. The affected states, for example, complained that DOE had abused its discretion in adopting the weighting scheme it did.

The following year, DOE used the *Siting Guidelines* to winnow down five potential sites to three candidate sites (in different host rocks) for the first repository. The three were to be investigated at depth and then compared. DOE's first approach to evaluating the sites drew strong criticism not only from the affected states but also from the National Academy of Sciences. A second approach, using multiattribute utility analysis, was considered technically more defensible. However, the Energy Secretary chose the sites that were ranked first, third, and fifth using that technique. He maintained that the methodology was "decision-aiding" not decision-controlling and that he had the discretion to take other considerations into account, such as diversity of host-rock types.

In addition, implementers preserve their discretion by controlling the technical foundations of the site-suitability criteria. If the ultimate desired outcome of any siting process is the development of a facility whose long-term performance must satisfy regulatory constraints, then technical expertise is essential.

But whose expertise counts? In most of the countries considered in this report, interested and affected parties have had no input at all into the development of site-suitability criteria. In two of the nations, Canada and the United Kingdom, the implementer offered an opportunity to comment on draft site-suitability criteria. Few groups or individuals responded; none of those comments resulted in changes to the draft version. DOE did solicit the views of numerous external parties as it was drafting its *Siting Guidelines*. Based on the large volume of comments received, the form of the first proposed siting regulation was altered in important ways, but its substance changed little between the early drafts and the rule that was submitted for concurrence to NRC. In sum, the development of site-suitability criteria typically has been a closed process that draws only on the implementer's expertise with occasional oversight by its regulator. Other interested and affected parties have had virtually no substantive influence. This dynamic, coupled with the discretion and flexibility that the implementer retains in defining and applying site-suitability criteria, has the potential to undermine public confidence in siting decisions that are made.

The development of site-suitability criteria typically has been a closed process. The implementer rarely accepts substantive recommendations from external parties.

Third, the siting process itself usually proceeds through three main stages. As noted above, the first involves screening a large number of areas (prospective settings) to determine which ones have the requisite geological properties that favor technical suitability. These assessments rely mainly on preexisting information and field surveys. In most countries, one or two dozen settings are evaluated, although more than 100 locations in both Finland and Germany were at least cursorily considered. Because the findings from the evaluations are rarely published, the implementer's rationale for discarding some locations and retaining others into the next stage is generally left unstated.

The smaller number of locations that emerge from the initial filtering stage are considered potential sites. They are evaluated using more detailed information contained in the literature. Preliminary surface-based investigations of the subsurface are often carried out. In most countries, only six to ten potential sites are studied. Based on whatever site-suitability criteria are in place, the implementer attempts to determine how well they are satisfied and derive estimates of how a repository might perform at each site. These assessments are typically published so that interested and affected parties understand the reason some locations are carried over to the next stage and others are not.

The next stage of the siting process—selecting *candidate sites*—is usually more formal and transparent. The implementer focuses on the handful of possibilities identified in the previous stage. More extensive surface-based tests are conducted to obtain a fuller understanding of the host rock. Models representing one or more disposal concepts are developed to project repository performance over tens of thousands of years. The implementer brings to bear both qualitative judgments and quantitative assessments to winnow down the potential sites. As noted above, under the 1982 Nuclear Waste Policy Act, DOE identified three candidate sites for detailed underground exploration and investigation. In Sweden, the implementer conducted a wide range of investigations at two sites—Laxemar, near the Municipality of Oskarshamn, and Forsmark, near the Municipality of Östhammar. As Figure 4 on page 26 shows, the two Swedish locations differed substantially in their projected performance; the Laxemar site did not comply with the regulatory standard at the 100,000-year compliance period, so the choice between the two candidate sites was simple and uncontroversial.

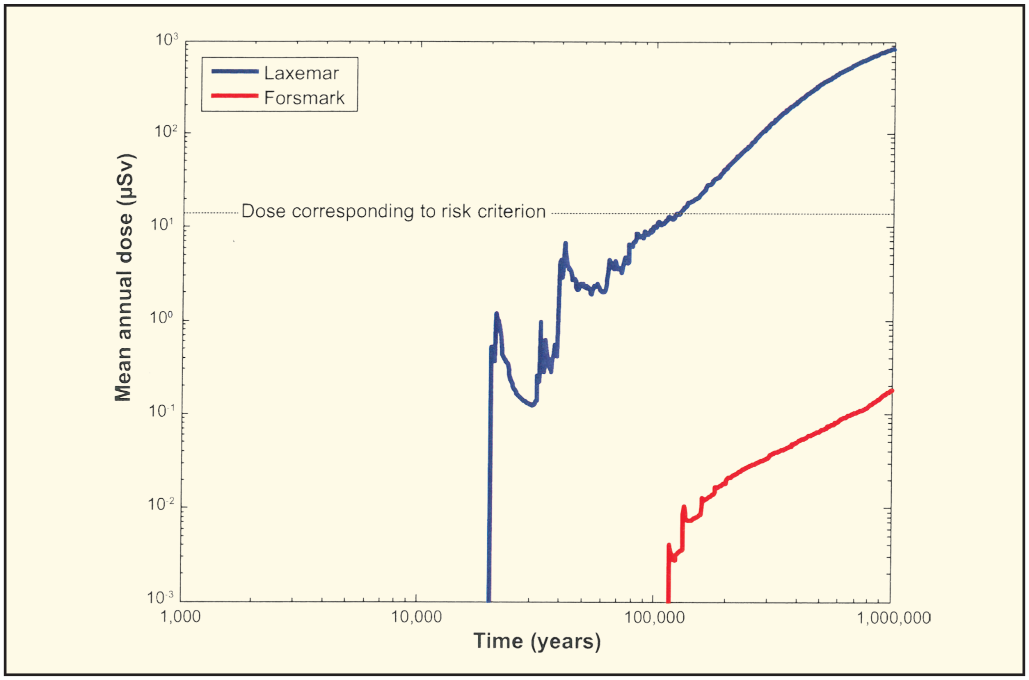

Figure 4. Results of the safety analysis for the candidate sites in Sweden. (Source: SKB 2010)

Social Acceptability Filters

In pluralistic democracies, it is axiomatic that what counts is not necessarily numbers (except in elections) but the intensity that drives individuals to organize to effect social and political change. Intensity, of course, is tightly connected to what people believe is at stake. When it comes to siting a deep-mined, geologic repository for HLW and SNF, the stakes generally appear to be high.

Some of those stakes are "standard," that is, they arise as a consequence of any large industrial, commercial, or institutional development or closure, such as those associated with a fossil fuel power plant, shopping mall, or prison. These standard effects include fluctuations in public health and safety, employment, taxation, traffic, noise, and environmental values.

Other stakes have been termed "special," that is, they surface as a consequence of attitudes, especially about things nuclear. As risk communication specialists and cognitive psychologists have noted, public perceptions of the hazards presented by radioactive waste rank it among the most dreaded, involuntary, unknown, consequential, and uncontrollable risks to which modern societies are exposed. These perceptions give rise to concerns about the stigmatization of communities and their agricultural products, the psychological distress experienced by individuals, and the loss in value of property located "too close" to a nuclear facility. For a further discussion of the difference between standard and special effects, refer to Box 4 on the next page.

Interested and affected parties are principally motivated by positive standard effects and negative special effects. Their actions can take on many different forms, depending in part on a nation's governance structure. Typically, Social Acceptability Filters include formal consent, demonstrations, referenda, partisan conflict, exercising a right of withdrawal, administrative or judicial reviews, and legislative action (or inaction). These responses manifest themselves in a variety of outcomes, ranging from accepting the selection of a repository site, maintaining a wait-and-see stance by monitoring events as they unfold, immobilizing the siting effort, or organizing resistance based on either flawed technical arguments or deficiencies in the process.

As observed above, implementers in most nations initially discounted the importance of the Social Acceptability Filter, believing that governmental power or scientific authority (or

Projects that significantly alter a community's physical, economic, and social environments stir reactions from governments, formal and informal organizations, and members of the general public. Risk communicators and cognitive psychologists have extensively explored these reactions in a wide variety of contexts. Those researchers distinguish between "standard" and "special" effects or impacts.

Standard effects arise from all such projects whether they are nuclear or nonnuclear. When a large industrial plant moves into town, its operation will affect the community's employment level, tax base, water and air quality, and housing stock. Impacts in these areas will also arise if a large industrial plant shuts down. Economists, city planners, and sociologists have studied and even modeled how these impacts are distributed within the community itself and in adjacent areas. Evaluation of these impacts, although hardly straightforward, benefits from the fact that they can more or less faithfully be monetized.

Psychometric research about perceptions of various types of risk clearly demonstrates that risk is viewed as a multidimensional concept, an understanding that departs in fundamental ways from the natural scientist or engineer's notion of expected death or morbidity. Those dimensions include, among other things, whether the risk is viewed as voluntarily accepted or imposed, whether it is familiar or unfamiliar, and whether it inspires dread or not.

Nuclear facilities in general and nuclear waste in particular evoke strongly negative associations along virtually all dimensions of perceived risk. Those associations give rise to ***special effects****,* the most important of which is stigmatization. Governments, formal and informal organizations, and members of the general public come to believe that nuclear facilities or waste taints nearby property, agricultural products, and communities as a whole.

Debates rage about how extensive and permanent those special effects might be. But there is no dispute about how powerfully they shape the discussion of siting a deep-mined, geologic repository. Concerns about stigmatization motivated demonstrations in Germany. Reactions among wine growers in southern France contributed to the elimination of one proposed repository site. The gaming industry and those connected with it worry that an accident involving a train carrying HLW and SNF to Yucca Mountain might deter tourists from traveling to Las Vegas.

Box 4. Standard and special effects

Passing sites through the Social Acceptability Filter has typically proved to be a major challenge for national waste-management programs.

both) was sufficient to enforce their siting choice. Certainly by the mid-1980s, those expectations proved unrealistic. The historical record clearly shows that national waste-management programs experienced significant disruptions when the implementer attempted to pass possible repository sites through the Social Acceptability Filter. With the exception of Finland, every country that has launched a siting effort has encountered major programmatic obstacles that lasted anywhere from two years to several decades. In France during the late 1980s, demonstrations in which several people were injured by police shut down the waste-management program. At about the same time in Sweden, public opposition to surface-based testing forced the implementer to reconstruct its siting process. In the United States, DOE canceled the program to find a site for the second repository because of intense public reaction. In Germany, the presumptive, but controversial, choice of Gorleben as a repository site paralyzed that country's efforts to dispose of its HLW and SNF for several decades.

Implementers did learn (but not always) from their experiences. One common response to the increased importance of social acceptability is to focus on locations where the impact of positive standard effects is high or where the influence of negative special effects is low. This strategy leads implementers to economically underdeveloped areas and to communities already hosting nuclear facilities. Thus, town leaders in Carlsbad, New Mexico, approached DOE to construct WIPP because the southwest region of the state needed an economic stimulus. The lack of developmental opportunities in the Meuse/Haute-Marne area in eastern France likely contributed to the communities' decision to volunteer to host a URL. The uncertain outlook facing the Sellafield nuclear complex in West Cumbria, England, certainly influenced three local councils to consider hosting a repository. The Finnish implementer was interested in the area around the Olkiluoto reactor site from the start. Similarly, the Swedish implementer eyed the municipalities where the Oskarshamn and Forsmark reactor sites are located. In the United States, the nuclear weapons complex sites in Washington State and Nevada were consciously thrown into the mix because public attitudes of the surrounding communities seemed favorable.

Implementers tend to search for possible repository sites in economically underdeveloped areas and around nuclear facilities.

A second response to the need to obtain social acceptability is to recognize the value of seeking some form of community consent early in the process. In Sweden, the municipalities permitted the implementer to carry out site-specific investigations. However, the communities retained near-absolute authority to prevent the government from issuing a license to construct a repository. As noted above, in France, communities in the Meuse/Haute-Marne areas formally volunteered to host a URL. In the United States, leaders in Carlsbad, New Mexico, invited the implementer to investigate sites nearby. Eventually, Congress, with support from the state's delegation, enacted legislation to pass the WIPP site through the Social Acceptability Filter. The Canadian implementer issued invitations for communities to express an interest in possibly hosting a repository. Twenty-two of them responded positively.

Although the historical record makes a convincing case that some type of consent-based siting process can lead to the final selection of a repository site, creating such a process does not offer any guarantee that a possible repository site will pass through the Social Acceptability Filter. Even before the damage to the reactors at the Fukushima Dai-ichi nuclear power plant caused by the Great East Japan Earthquake-Tsunami Disaster, the Japanese implementer had been trying for nearly a decade to find volunteers to explore the possibility of hosting a deep-mined, geologic repository. The mayor of the one township that volunteered was recalled. The Japanese government revised this consent-based effort in 2013 and intends to introduce another approach in the near future where the implementer first identifies technically suitable sites. The implementer in the United Kingdom experienced virtually the same response as in Japan when it invited communities to explore the ramifications of hosting a repository. Two boroughs and one county council in Cumbria responded positively. Because the process required agreement at both the borough and county levels, when the Cumbria County Council ultimately decided to withdraw, the process ground to a halt. The implementer substantially reconstituted its proposed siting approach. A new process has been created, one that still involves some form of voluntarism but may eliminate the close partnership between the implementer and the host communities that characterized the earlier effort.

Creating consent-based siting processes offers no guarantee that a possible repository site will pass through the Social Acceptability Filter.

Consent-based siting processes must find satisfactory ways of allocating decision-making power between the central and subordinate governments.

National experiences with siting a deep-mined, geologic repository suggest that at least two conditions must be met for a consent-based process to succeed. First, the process must accommodate national political norms about how power is distributed between the central government on the one hand and local/state/regional/tribal governments on the other. In Scandinavian societies, allocating strong powers to municipalities is a long-standing tradition, well established years before anyone conceived of applying it to the siting of a repository. That communities should be able to exercise vetoes in the siting process for a repository was considered unexceptional.

In nations whose political structures reflect other traditions, however, determining the role of lower levels of government (as well as Native American tribes in the United States, which are sovereign governments) often requires considerable creativity. In France, localities possess the power to volunteer for a URL. But once the power is exercised, decision-making authority transfers to the national parliament. In the United Kingdom, Government initially required that the county council had to concur. As just noted, when the Cumbria County Council declined, the process stopped. The breadth of a county's power has not yet been specified in the newly adopted siting strategy.

This challenge in allocating power between the center and the periphery is particularly acute in societies that embrace federalism. In Germany, the standoff between the Federal and Lower Saxony governments, especially when they were controlled by different political parties, has persisted for at least 20 years. A new law, acceptable to all parties as well as the German states (*Länder*), establishes the framework for creating a new siting process. It remains to be seen how that legislation will be implemented. In Switzerland, the central government has allowed the cantons to play a strong, but essentially advisory, role. The cantons can influence where a repository's surface facilities will be located but are blocked from evaluating the implementer's arguments about the postclosure safety case. The presumption is that the local populations will accept the results of rigorous technical evaluation in the siting process. That process recently slipped by several years, so it is unclear whether this optimistic belief will be borne out. In Japan, the unwillingness of communities to volunteer to explore the possibility of hosting a repository has led the central government to rethink fundamentally a consent-based process that had yielded no results.

In the United States, states have the power to object to a repository siting decision made by the President. The State of Nevada exercised this right by notifying Congress when Yucca Mountain was formally chosen in 2002. Under the law, however, a majority vote in both the Senate and the House of Representatives overrode the state's objections. Thus, consent was sought, but it was withheld to no avail.

A second requirement for successfully implementing a consent-based siting process relates to the behavior of the implementer. Those responsible must be widely seen as trustworthy and committed to operating in a transparent manner. In Finland, the implementer maintained its position of trust by not taking advantage of its strong bargaining position *vis à vis* the Eurajoki municipality. The French and Swedish implementers embedded themselves in the communities where they sought to build a repository. By all accounts, strong bonds of trust have been formed. DOE officials and contractors have been highly regarded by the Carlsbad, New Mexico, community. That trust was fostered, at least in part, by DOE's early decision to locate its staff and contractors there. In rather sharp contrast, it took only a few years for trust to be completely lost between DOE and officials from the State of Nevada, even though leaders of the county where Yucca Mountain is located remain supportive.

Trust in the implementer and the implementer's commitment to transparency significantly affects whether a consent-based process results in the passage of a site through the Social Acceptability Filter.

In two respects, trust and transparency play an important role in facilitating the passage of a site through the Social Acceptability Filter. First, trust can help to make an implementer's actions less contentious. Any decision that an implementer makes will have a set of consequences. For example, the choice could affect cost, risk, economic development, and even the reservoir of trust that the implementer enjoys. As a practical matter, for most complex public policies, it simply is not possible to maximize the positive consequences of any option while at the same time minimizing the negative ones. Tough trade-offs have to be made. When such situations inevitably arise, how interested and affected parties interpret the implementer's conduct becomes critical. If the reservoir of trust is full, they are more likely to accept the implementer's actions, especially if the rationale for the decision is transparent. Moreover, the reservoir of trust is not likely to be appreciably reduced. However, if the reservoir is already depleted, the decision is more likely to be construed as part of a pattern that ignores those parties' interests. In that case, the reservoir of trust could be further compromised, and a vicious cycle could develop in which accepting the implementer's actions becomes increasingly problematic.

Second, advancing the case for the safety of a disposal concept implemented at a specific site requires complex technical arguments. By their very nature, such arguments may be open to differing, even incompatible, interpretations that are not easily resolvable. As a consequence, uncertainty will attach to performance projections. Even if the uncertainty can be bound by conventional techniques, such as sensitivity and what-if analyses, interested and affected parties may accept a different interpretation than that of the implementer. If the implementer has demonstrated its trustworthiness, those parties are more likely to accept its assessment. Otherwise, questions may continue to be raised, creating fertile ground for suspicion and opposition.

In 2012, the BRC recommended that the United States establish a consent-based siting process. The Obama Administration has accepted that advice. The details of what such a process will look like remain vague, perhaps necessarily so. Indeed, inventiveness and flexibility are required if the long-standing tradition of federal dominance is to be revised. The historical record reveals no easy recipe for structuring a consent-based siting process. However, certain strategies seem to have been important ingredients in at least some of the countries that have successfully adopted such an approach. These strategies are listed in Box 5 on the next page.

- Beginning far in advance of a specific siting study, communicate and engage with interested and affected parties to discuss the overall goals and objectives of national radioactive waste-management programs.
- Use multiple techniques and approaches to communicate and directly engage with interested and affected parties.
- Embed the implementer's representatives within the community.
- Create clear rules—that are agreed to in advance—to govern the relationship between the implementer and the community.
- Establish a group that is broadly representative of the community, to foster ongoing interactions with the implementer.
- Specify the basis for when, why, and how a community can withdraw from the siting process.
- Provide sufficient funding to allow a community to participate fully in the process.
- Provide independent review of the implementer's technical arguments either by experts chosen by the community or by an ongoing external group.
- Encourage the implementer to be open and responsive to questions and challenges from the community.
- Create a partnership between the community and the implementer to support repository development if the former agrees to host the facility.
- Clearly articulate the benefits the community is likely to receive from hosting a deep-mined, geologic repository.

Box 5. Elements of successful consent-based siting processes

Interdependence of the Technical Suitability and Social Acceptability Filters

Although the Technical Suitability and Social Acceptability Filters can be described and analyzed independently, important aspects of siting processes can be understood only by inquiring how the two interact, as depicted in Figure 5.

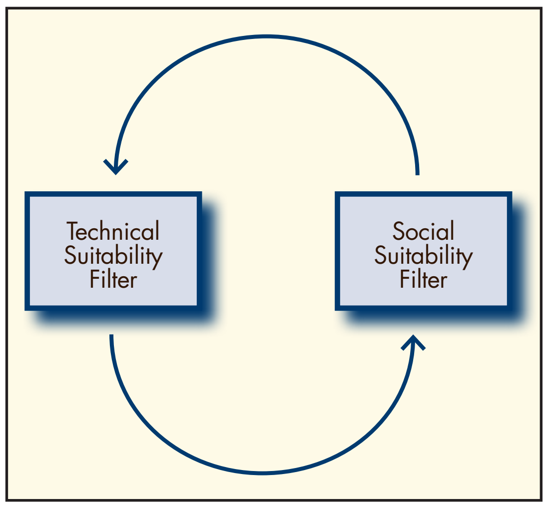

Figure 5. Interdependence of the two filters

One example of this interdependence is how the *prima facie* simplicity and analyzability of a disposal concept may affect the understanding of its promise and, by extension, its social acceptability. To be sure, the constraints imposed by geology may limit a nation's choices, and the simplicity and analyzability of any concept will necessarily depend on important details. Nonetheless, the Belgian approach for disposing of HLW in a Boom clay formation using a "Supercontainer" is more elaborate than the French concept for disposing of the same material directly in the Callovo-Oxfordian argillite. The Swedish KBS-3 disposal concept, which achieves waste isolation and containment by using a copper canister surrounded by bentonite clay emplaced in a crystalline rock formation, appears more intuitively understandable than the Yucca Mountain disposal concept, which involves water flow through both unsaturated and saturated formations coupled with an elaborate engineered barrier system composed of a robust waste package and drip shields.

Sites for which technical suitability can be demonstrated by relatively simple analyses may face fewer challenges in passing through the Social Acceptability Filter.

Moreover, the case for the KBS-3 concept is strengthened by the use of natural analogues. The Swedish implementer can show the public samples of elemental copper nodules that reside undisturbed in crystalline rocks that are millions of years old. DOE searched for, but never truly found, compelling analogues to support its position about the performance of the Yucca Mountain repository system. Although it is difficult to separate the degree to which simplicity and analyzability contributed to social acceptance in Sweden—other factors undoubtedly played a part—the ease by which the KBS-3 concept could be communicated to interested and affected parties certainly facilitated the implementer's task.

The order in which a site passes through the filters reflects a judgment about which poses the greatest challenge and runs the greatest risk of failure.

A second example of the interdependence of technical and social aspects is how national laws and regulations determine the order in which a site passes through the Technical Suitability and Social Acceptability Filters. In the past, when repository siting was largely the domain of scientific and engineering specialists, the difficult problem was believed to be evaluating the suitability of a particular geologic formation. The authority granted to the technical professionals because of their expertise was considered so legitimate that their choices were subject to only little social control until late in the siting process. Not surprisingly, then, concentrating on demonstrations of site suitability became the first order of business in most countries. But that strategy of decision-making met with repeated setbacks, in Canada, France, Germany, Sweden, and the United States. The technical problem became more of a *socio-technical challenge*, and the difficult problem became obtaining social acceptability. Consent-based siting then became the new model, and passing a site through the Social Acceptability Filter took precedence.

Experience has shown, however, that in some countries a consent-based siting process that relies solely on broad and general Exclusion Criteria at the start may be ineffective. Solving this problem requires that a more elaborate disposal concept be formulated, coupled with at least a plausible demonstration of suitability. Only then, the thinking in the United Kingdom and Japan goes, will communities be willing to step forward. After experiencing difficulties, those responsible in both nations appear to have yet again fundamentally reordered passage through the filters. Technical evaluations will be given greater emphasis at the beginning of the process.

The siting processes used in two countries, Germany and Switzerland, have countered the recent trend toward consent-based siting. In both nations, the political culture places a strong emphasis on the value of science and engineering. Determining the technical suitability of a site, therefore, has taken precedence. In Germany, the newly enacted siting process is likely to endorse passage of sites first through the Technical Suitability Filter. In Switzerland, the 2008 Sectoral Plan already explicitly does so.

A third example of the interdependence of the Technical Suitability and Social Acceptability Filters relates to the role that the political estate and interested and affected parties play in designing Technical Suitability Filters.

Crafting indicators of suitability—whether they are broad and general Exclusion Criteria, Host-Rock-Specific Criteria, or Generic Criteria—is a crucial step in most siting processes. As discussed above, implementers are generally resistant to revise draft site-suitability criteria. Legislators' responses to public concerns about the requirements for siting a repository, however, are not as uniform. Most take a hands-off approach, which they justify by a belief that, as experts, implementers are best positioned to understand the technical complexities associated with suitability. This perspective dominates, for example, in Finland, Sweden, and Switzerland.

In contrast, legislators in the United States and France recognize that the process for selecting a repository site is highly charged and consequential. In the United States, senators and representatives inserted language into the Nuclear Waste Policy Act that instructed DOE how to write its *Siting Guidelines* with respect to population density, seasonal recreation activity, and proximity to public water supplies.

Although implementers are generally resistant to revising draft site-suitability based on public comments, in the United States and France, legislators took the views of the public into account by enacting some specific site-suitability criteria.

In France, a formal national public debate was held in 2005 to elicit views about the future course of radioactive waste management. One conclusion that arose from these discussions was that any approach taken to develop a deep-mined, geologic repository had to be "reversible." This sentiment was accepted when the French Parliament enacted legislation the following year.

Thus, in both nations, legislators believed that it was their duty and responsibility to ensure that their constituents are not exposed to undue risk, calculated or perceived, from the construction of radioactive waste-management facilities in their communities.

A fourth example of the interdependence of the Technical Suitability and Social Acceptability Filters applies especially to efforts that rely on Generic Criteria to select sites. In that case, implementers may not be able, even in principle, to specify sharply defined criteria that can serve as clear benchmarks against which a site's suitability might be assessed. Terms such as "likely," "potentially adverse condition," "sufficient," and "favorable" unavoidably lie at the heart of such rules and regulations that govern the search for a site.

Because of their intrinsic ambiguity, implementers enjoy considerable latitude in interpreting and applying these terms and concepts. As noted above, DOE's decisions when evaluating prospective settings in crystalline rock for the legally mandated second repository and its narrowing of five potentially acceptable sites down to three candidate sites for the first repository are pointed examples. In both cases, the necessary exercise of discretion by the implementer opened the door to charges, justified or not, of unfairness and bias by interested and affected parties. The resulting political turbulence in both cases led to major changes in the country's waste-management program.

A siting process that relies on Generic Criteria is especially vulnerable to charges of unfairness and bias.

To be sure, the implementer's choices about methodology and its reading and construal of the findings from investigations involve exercising discretion even when Host-Rock-Specific Criteria structure the siting process. But the implementer can be held more accountable when the criteria are less rather than more ambiguous.

A fifth example of the interdependence of the Technical Suitability and Social Acceptability Filters concerns public attitudes toward nuclear power. Even if a nation has not forged a legal link between the operation of nuclear reactors and a viable approach for the long-term management of HLW and SNF, the physical connection is undeniable. Interested and affected parties that oppose the use of commercial nuclear energy may tactically block the development of a repository as a means to achieve their strategic objective. Conversely, parties that favor continued or expanded use of nuclear power may tactically push for an early decision about a repository to achieve their strategic objective.

Controversy in some nations about the future role of nuclear power has profoundly affected the siting process. In others, it has had only a marginal impact.

Since the mid-1970s, a strong linkage has been maintained in Sweden between the production of commercial nuclear power and the industry's obligation to develop expeditiously programs to manage SNF over the very long term. At least to date, neither nuclear opponents nor supporters have been able to use efforts to develop a repository as a vehicle for advancing their policy preferences. In contrast, the major political parties in Germany have taken opposing stands on nuclear power for nearly 20 years. This political conflict is a significant contributor to the paralysis of that nation's waste-management program. In the United Kingdom, debate persists about whether so-called "legacy waste" should be managed differently from the yet-to-be-created waste produced by new nuclear power plants.

In the United States, the situation is not nearly as straightforward. Courts in the past have permitted the regulator, NRC, to sever the link between nuclear power production and the availability of a repository by expressing "confidence" that the disposal of HLW and SNF was technically feasible and would be available. With the future of the Yucca Mountain repository project now in limbo, NRC's "confidence" was successfully challenged in court. NRC revisited the issue and, in 2014, determined that SNF can be safely stored in dry storage casks beyond the lifetime of the nuclear power plants. This decision also has been challenged, although the case is still pending. If the regulator's determinations are not upheld, then the consequences for the continued operation of nuclear power plants and the urgency of the need for a repository could be profound.

The final example of the interdependence of the Technical Suitability and Social Acceptability Filters relates to the idea of informed consent.

Characterization of a site deep beneath the surface is required to protect against surprises either about the properties of the geologic formation or about the site-specific fit between a disposal concept and the host rock. Surface-based tests can probe the subsurface using geophysical imaging, such as seismic reflection or electrical methods, and samples and information from drilling to identify a suitable site. Surface-based testing is typical of other geoscience activities, such as the exploration for mineral and hydrocarbon deposits. In those cases, surprises are not unusual. Huge investments in time and money may precede a "dry hole" at the end of an extended exploration campaign. Perhaps the lesson is that success in geological exploration is a bit of a surprise and that failure must be anticipated and accepted. Once a potential site is identified, there is no substitute for direct characterization of the *in situ* conditions.

National waste-management programs recognize the importance of site investigations at depth. Typically, they construct URLs where studies are mounted either at a candidate site itself or at a location that strongly mimics the conditions likely to be found at a candidate site. Without exception, URLs have yielded valuable technical information. The French safety case relies heavily on the investigations carried out at the URL near Bure. The Yucca

Mountain site-suitability recommendation depended on information collected in the Exploratory Studies Facility. The Swiss safety case for a repository in Opalinus clay was supported by data collected at the Mont Terri Laboratory. The KBS-3 concept relied heavily on information gathered at the Äspö Hard Rock Laboratory.

Informed consent of a community to host a deep-mined, geologic repository requires extensive underground site characterization. Underground research laboratories in the identified hydrogeologic environment and at the same depth as the candidate site can be constructed to provide important technical information.

In every country where a siting process that includes some form of consent has been implemented, consent is usually sought at the earliest stages and can be withdrawn up until the point at which the implementer must make substantial investments to carry out studies underground. In those instances, when the right of withdrawal can be exercised has emerged as a point of contention, as it did, for example, in the United Kingdom. The more detailed the information available when the last opportunity for withdrawal presents itself, the more informed consent will be.

The United States was an important exception to the general practice. Under the original Nuclear Waste Policy Act, investigations were to be conducted deep underground at three candidate sites. Only afterward would the President recommend to Congress that it ratify where a repository could be constructed. At that point, a state could contest the recommendation, again subject to a legislative override.

Observations, Findings, and Recommendations

Siting a deep-mined, geologic repository is a tough *socio-technical* challenge. Not surprisingly, the experience doing so has been mixed. Of the two dozen attempts in ten nations that have taken place over the years, six are still on track; of the four sites selected, applications for construction authorizations are active in three. Notwithstanding this history, the Board strongly agrees with the international consensus within the scientific and engineering communities and among implementers and regulators that developing such a facility is technically feasible and provides a compelling level and duration of protection.

Thus, the Board advises DOE that it should not pursue any disposal strategy that might distract from focused efforts to develop a deep-mined, geologic repository.

As this report notes at the start, the United States is in the midst of a debate of how to manage for the long term the ever-growing stocks of SNF and HLW. The fate of the congressionally approved site at Yucca Mountain for the nation's first deep-mined, geologic repository for HLW and SNF is now in limbo. The Obama Administration's policy is to find a new site through a consent-based process. In fact, the Administration is proposing to develop two repositories, one to dispose of defense HLW (and perhaps some defense SNF) and another for the remainder of the inventory. All the while, supporters of the Yucca Mountain project are working to revive it.

If policymakers determine that a new siting process should be launched for either the nation's first or second repository, a number of questions will have to be addressed, including the following:

- What organization should be responsible for implementing the new siting effort?
- How should it be financed?
- How should decision-making power be allocated between communities, tribes, and states on the one hand and the federal government on the other?

These are exceedingly important issues, but they lie beyond the Board's technical charter.

But consistent with its legislative mandate, the Board does advance four recommendations that are limited to the technical practices that DOE (or some other organization) might undertake in the future.

1. Because of the geological diversity in the United States, it may not be possible to choose a single disposal concept in advance of the site-selection process. (The Finns and the Swedes were able to do so because a single rock type, crystalline rock, underlies virtually all of both countries.) Consequently, despite their limitations, Generic Criteria will have to provide the initial foundation for any new set of site-suitability criteria. DOE's 1984 *Siting Guidelines,* a striking example of Generic Criteria, is consistent with international practice and is technically defensible. A different approach, embodied in DOE's 2001 Yucca Mountain-specific site-suitability regulation, relies on probabilistic performance assessment. Putting aside the ongoing debate over the utility and validity of that methodology, using it to winnow down sites is inappropriate and technically questionable. The data needed to employ sensibly such an approach simply are not available at the earliest stages of any siting effort.

   Therefore, the Board recommends that DOE's 1984* Siting Guidelines *be adopted as a sound basis for developing any new rules that might structure a future siting process. A site-suitability regulation that relies on a technically complex performance assessment, such as DOE's 2001 regulation for Yucca Mountain, does not provide a sound basis for the initial stages of site selection.

2. DOE applied the 1984 *Siting Guidelines* to compare locations when it reduced the number of prospective settings for the second repository. In that case, all the sites were in crystalline rock formations. Using Generic Criteria when Host-Rock-Specific Criteria would have sufficed unnecessarily complicated matters. The development of new guidelines should anticipate this situation. Adding Host-Rock-Specific Criteria that are disposal-concept specific would simplify and make more transparent the technical basis for DOE's decisions in the future.

   Therefore, the Board recommends that the 1984* Siting Guidelines *be supplemented with Host-Rock-Specific Criteria that are applicable to the geology-specific concepts (including relevant engineered barriers) that have been advanced for disposing of HLW and SNF in salt, crystalline rock, or clay/shale formations and their associated environmental settings.

3. DOE also used the 1984 *Siting Guidelines* to winnow the five potential sites for the first repository down to three candidate sites. DOE exercised its legitimate discretion to interpret ambiguous language in the rule and to determine how its multiattribute utility analysis methodology should be carried out to distinguish among sites. In both that case and the down-selection of prospective settings for the second repository, charges of unfairness were leveled that could not be dispelled neatly and persuasively. There is a fine line between protecting the discretion required for bureaucratic flexibility and enlarging the domain of discretion to the point that bureaucratic decisions appear unaccountable. If new (or revised) guidelines are written, they must be scrutinized carefully to ascertain on which side of that line they fall. Erring on the side of reducing discretion is a conservative approach, but one that is more likely to be viable in the long term.

Therefore, the Board recommends that, to the greatest extent possible, the development of any new site-suitability criteria minimize the ambiguity that facilitates the implementer's discretion in applying them, helping ensure the objectivity of the process and public confidence in its outcome. If, at any point during the siting process, the criteria need to be changed, the implementer should use a transparent and meaningfully participatory process to do so.

4. As investigations related to siting proceed at the surface as well as in laboratories, knowledge is gained about the potential performance of a proposed repository system. That knowledge is usually supplemented with the construction of underground research laboratories in the same hydrogeologic environment as the candidate site. Thus, the chances of scientific and technical surprises arising are reduced even if they cannot be completely eliminated. Communities asked to consent to the choice of site generally are concerned about when a right of withdrawal can be exercised because disagreements between the implementer and the community may arise over whether any surprises encountered can be worked around or whether they automatically disqualify a site. The 1982 Nuclear Waste Policy Act uniquely requires that investigations at depth be completed before a final decision on selecting a repository site can be made. The implementer and the affected community/state both benefit from investigations carried out at depth where the repository will be built. Resources might not be expended in vain. Giving consent or withholding it until the time of "full disclosure" permits a more informed choice.

   Therefore, the Board recommends that any new siting process preserve the requirement in the 1982 Nuclear Waste Policy Act that a final choice of site await extensive underground characterization.

References

Ackoff, R. 1974. *Redesigning the Future*. New York: Wiley.

Blue Ribbon Commission on America's Nuclear Future (BRC). 2012. *Report to the Secretary of Energy*. Washington, DC.

Department of Energy. 1984. "General Guidelines for the Preliminary Screening of Potential Sites for a Nuclear Waste Repository." *10 Code of Federal Regulations 960*.

Nuclear-News Net. 2012. http://nuclear-news.net/2012/09/23.

Obama, B. 2015. "Presidential Memorandum—Disposal of Defense High-Level Radioactive Waste in a Separate Repository." March 24, 2015.

Swedish Nuclear Fuel Supply and Waste Management Corporation (SKB). 2010. *Comparative Analysis of Safety-Related Site Characteristics*. TR-10-54. Stockholm, Sweden.

Acronym List

BRC	Blue Ribbon Commission on America's Nuclear Future
DOE	Department of Energy
EPA	Environmental Protection Agency
HLW	high-level radioactive waste
NRC	Nuclear Regulatory Commission
NWTRB	Nuclear Waste Technical Review Board
SNF	spent nuclear fuel
URL	underground research laboratory
WIPP	Waste Isolation Pilot Plant

Glossary*

argillite A compact rock derived from either claystone, siltstone, or shale, that is more indurated than its constituent source rock but less laminated and fissile than shale and lacking the cleavage of slate.

a**ssessment, performance** An assessment of the performance of a system or subsystem and its implications for protection and safety at a planned or an authorized facility.

assessment, probabilistic A simulation of the behavior of a system defined by parameters, events, and features whose values are represented by a statistical distribution. The analysis gives a corresponding distribution of results.

backfill The material used to refill excavated parts of a repository (drifts, disposal rooms, or boreholes) during and after waste emplacement.

barrier A physical or chemical feature that prevents or delays the movement of radionuclides or other material between components in a system—for example, a waste repository. In general, a barrier can be an engineered barrier that is constructed or a natural geological, geochemical, or hydrogeological barrier.

basalt A dark-colored mafic igneous rock, commonly extrusive as lava flows or cones but also intrusive as dikes or sills.

bentonite A soft light-colored clay formed by chemical alteration of volcanic ash. Bentonite has been proposed for backfill and buffer material in many repositories.

borehole A cylindrical excavation made by a drilling device. Boreholes are drilled during site investigation and testing and can also be used for waste emplacement.

---

*Most of these definitions have been taken from *International Atomic Energy Agency, Radioactive Waste Management Glossary*, 2003 Edition, Publication 1155, (IAEA: Vienna, 2003). The definitions of some terms have been altered to make them more applicable to this report, and other terms have been added. The IAEA is not responsible for those changes. Definitions of geologic terms are derived from the *American Geological Institute Glossary of Geology*, Third and Fourth Editions (AGI: Alexandria, VA, 1987 and 1997).

characterization, site Detailed surface and subsurface investigations and activities at candidate disposal sites for obtaining information to determine the suitability of the site for a repository and to evaluate the long-term performance of a repository at the site.

clay A sediment composed of rock or mineral fragments smaller than 4 microns. Clays typically have relatively low permeability and relatively high capacity for sorption of positively charged chemicals.

closure Administrative and technical actions directed at a repository at the end of its operating lifetime—for example, covering the disposed of waste (for a near-surface repository) or backfilling and/or sealing (for a geological repository and the passages leading to it)—and termination and completion of activities in any associated structures.

compliance period The length of time over which a repository is expected to satisfy either the dose constraint or the risk limit.

containment Methods or physical structures designed to prevent the dispersion of radioactive substances.

crystalline rock *See* **rock, crystalline.**

decommission Administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility. This does not apply to a repository or to certain nuclear facilities used for mining and milling of radioactive materials, for which the term “closure” is used.

drift A horizontal or nearly horizontal mined opening.

engineered barrier system The designed, or engineered, components of a repository, including waste packages and other engineered barriers. *See* also **barrier.**

fuel cycle All operations associated with the production of nuclear energy, including mining and milling, processing and enrichment of uranium or thorium, manufacture of nuclear fuel, operation of nuclear reactors, reprocessing of nuclear fuel, related research and development activities, and all related radioactive waste management activities including decommissioning.

fuel, spent nuclear (SNF) Nuclear fuel removed from a reactor following irradiation that is not intended for further use in its present form because of depletion of fissile material, buildup of poison, or radiation or other damage.

geologic repository *See* **repository, deep-mined, geologic.**

glass (waste matrix material) An amorphous material with a molecular distribution similar to that of a liquid but with a viscosity so great that its physical properties are those of a solid. Glasses used in the solidification of liquid high-level waste are generally based on a silicon-oxygen network. Additional network formers, such as aluminum, or modifiers, such as boron, lead to aluminosilicate or borosilicate glass.

granite Broadly applied, any holocrystalline quartz-bearing plutonic rock. The main components of granite are feldspar, quartz, and, as a minor essential mineral, mica. Granite formations are being considered as possible hosts for geological repositories.

groundwater Water that is held in rocks and soil beneath the surface of the earth.

high-level waste (HLW) *See* **waste, high-level.**

host rock *See* **rock, host.**

implementing organization The entity charged under law (and its contractors) that undertakes the siting, design, construction, commissioning, and operation of a nuclear facility.

***in-situ* testing** Tests to determine the characteristics of the natural system that are conducted within a geological environment that is essentially equivalent to the environment of an actual repository.

license Permission granted by the government on the advice of or by a regulatory authority to perform specified activities related to a facility or an activity. These activities may include construction, operation, or closure of a repository. The holder of a current license is termed a "licensee."

lithostatic pressure Pressure due to the weight of overlying rock and/or soil and water.

long-term In radioactive waste disposal, refers to periods of time that are on the order of hundreds of thousands of years.

model A conceptual, analytical, or numerical representation of a system and the ways in which phenomena occur within that system, used to simulate or assess the behavior of the system for a defined purpose.

nuclear fuel cycle *See* **fuel cycle.**

nuclear waste *See* **waste, radioactive.**

package, waste The waste form and any container(s) and internal barriers (e.g., absorbing materials and liners), prepared in accordance with the requirements for handling, transport, storage, and disposal.

postclosure The period of time following the closure of a repository and the decommissioning of related surface facilities. *See* also **closure, decommission.**

probabilistic assessment *See* **assessment, probabilistic.**

radionuclide A nucleus of an atom that possesses properties of spontaneous disintegration.

regulator An authority or a system of authorities designated by the government of a nation as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby for regulating the siting, design, construction, commissioning, operation, closure, decommissioning, and, if required, subsequent institutional control of nuclear facilities or specific aspects thereof.

repository, deep-mined, geologic A facility for disposal of radioactive waste located underground (usually several hundred meters or more below the surface) in a geological formation intended to provide long-term isolation of radionuclides from the biosphere.

reprocessing A process or operation the purpose of which is to extract radioactive isotopes from spent fuel for further use or to separate out various waste streams.

risk A multiattribute measure expressing hazard, danger, or chance of harmful or injurious consequences associated with actual or potential exposures. It reflects the probability that specific deleterious consequences may arise and the magnitude and character of such consequences.

rock A solid aggregate composed of naturally occurring substances including either one or more minerals, glasses, or organic matter.

rock, crystalline A generic term for igneous rocks and metamorphic rocks as opposed to sedimentary rocks. *See* also **granite.**

rock, host A geological formation in which a repository is located.

rock, igneous Rock or mineral that solidified from molten or partly molten material. This includes plutonic rock such as granite and volcanic rocks such as basalt.

rock, sedimentary A type of rock resulting from the consolidation of loose material that has accumulated in layers. The layers may be built up mechanically or by chemical precipitation.

safety case An integrated collection of arguments and evidence for demonstrating the safety of a facility. This will normally include a safety assessment but could also typically include independent lines of evidence and reasoning on the robustness and reliability of the safety assessment and the assumptions made therein.

salt In geology, generally used to refer to naturally occurring halite (sodium chloride).

sedimentary rock *See* **rock, sedimentary.**

shale A consolidated clay rock that possesses closely spaced, well-defined laminae.

site The area containing, or under investigation of its suitability for, a nuclear facility (e.g., a repository). It is defined by a boundary and is under effective control of an operating organization.

site characterization *See* **characterization, site.**

site selection *See* **siting.**

siting The process of selecting a suitable disposal site. The process comprises the following stages: concept and planning, area survey, site characterization, and site selection. For a site to be selected, it must be both technically suitable and socially acceptable.

special effects Impacts that derive from risk perceptions about hazardous facilities, such as nuclear power plants and radioactive waste repositories. Among those special effects is the stigmatization of the community and its agricultural products.

spent nuclear fuel (SNF) *See* **fuel, spent nuclear.**

standard effects Impacts associated with the development or closure of infrastructure, such as factories, institutions, and transportation projects. Among those standard effects are changes in the tax base, employment, and the physical environment.

storage The holding of spent nuclear fuel or of radioactive waste in a facility that provide for its containment, with the intention of retrieval.

storage, interim *See* **storage.**

transuranic waste *See* **waste, transuranic.**

tuff A rock composed of compacted volcanic ash.

underground research laboratory A facility where *in-situ* testing can take place.

waste Material in gaseous, liquid, or solid form for which no further use is foreseen.

waste, high-level (HLW) The radioactive liquid containing most of the fission products and actinides present in spent fuel—which forms the residue from the first solvent extraction cycle in reprocessing—and some of the associated waste streams; this material following solidification; spent fuel (if it is declared a waste); or any other waste with similar radiological characteristics. Typical characteristics of HLW are thermal powers that are above about 2 kW/m^3 and long-lived radionuclide concentrations exceeding the limitations for short-lived waste.

waste, radioactive Waste that contains or is contaminated with radionuclides at concentrations or activities greater than clearance levels as established by the regulatory body. It should be recognized that this definition is purely for regulatory purposes and that material with activity concentrations equal to or less than clearance levels is radioactive from a physical viewpoint.

waste, transuranic Alpha-bearing waste containing nuclides with atomic numbers above 92, in quantities and/or concentrations above regulatory limits.

waste disposal *See* **disposal.**

waste form Waste in its physical and chemical forms after preparation for disposal.