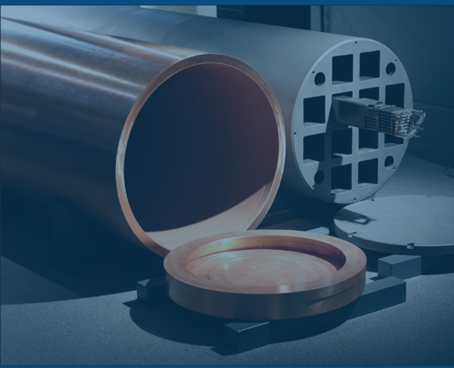

Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel

Detailed Analysis

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

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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.

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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

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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

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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-suitability 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 outcome.

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.

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 flex-

ibility 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.[1] 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

This state of affairs has historical roots that even today frame and constrain the work of dedicated individuals in the United States and abroad. In the beginning, the scientific and engineering communities believed that radioactive waste management was a relatively straightforward technical task and not a *socio-technical* challenge. By simplifying what needed to be done, the communities provided a rationale for policymakers to do nothing right away, other than taking essential palliative measures. Later on, as the complexity of the issue became better appreciated, not only by specialists but by affected constituencies as well, the political environment that deferred to the authority of expertise had undergone

[1] Of the two dozen discrete attempts to find a site for a repository, just six—in Canada, China, Finland, France, Sweden, and Switzerland—have not been derailed. The nuclear power generating capacity in those six nations accounts for 28.4 percent of the worldwide total (Nucleonics Week 2014).

significant change. The notion of "scientific truth" was supplemented with the notion of "scientific uncertainty." The idea that the values of technical specialists represented well the values of the larger society came to be viewed as outmoded and was ultimately discredited. As the social consensus on the worth of the nuclear enterprise weakened, waste-management efforts struggled, often quite unsuccessfully, to remain above the fray.

In the atmosphere that now surrounds discussions of the vexing problem of what to do with HLW and SNF, the technical community has advanced several creative long-term strategies to isolate, contain, or transmute the by-products. So far, every nation that has selected an approach has opted for disposal in deep-mined, geologic repositories. Reflecting this agreement, the Radioactive Waste Management Committee of the Nuclear Energy Agency (NEA), an international organization, held that constructing a repository is "technically feasible" and would provide "a unique level and duration of protection" (NEA 2008:7). In the United States, the Department of Energy (DOE) currently has the responsibility to develop a deep-mined, geologic repository. The Nuclear Regulatory Commission (NRC) must approve any application that DOE submits to develop such a facility.

In 1987, Congress established a third organization, the Nuclear Waste Technical Review Board (Board or NWTRB), as an independent federal agency. Its mandate is to evaluate the technical and scientific validity of subsequent actions taken by the Secretary of Energy to implement the 1982 Nuclear Waste Policy Act (NWPA). As part of its ongoing oversight, the Board has written this report to apprise policymakers and the public about one crucial, but challenging, element common to all national nuclear waste-management programs: selecting a site for a repository.[2] To develop insights into how to design such a process and to describe the socio-technical challenges that have arisen, the report relies on the historical record, including two dozen siting experiences in ten countries.

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 DOE submitted a license application to NRC in 2008 to construct this facility, the project is now in limbo. The Obama Administration determined in 2010 that the Yucca Mountain project was "unworkable" and 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, DOE recently prepared studies supporting the view that separate repositories should be developed to dispose of many types of DOE-owned HLW and SNF (DOE 2014b; DOE 2015). Subsequently, President Barack Obama signed a memorandum in 2015 finding that a separate repository at least for defense HLW was "required" under the NWPA (Obama 2015). DOE has indicated that it will launch a process to site such a facility (Moniz 2015).

As a technical body, the Board takes no position in these repository-siting debates. However, because the NWPA places a legislative limit on the amount of HLW and SNF that can be disposed of at the first facility (wherever it is located), a second one might have to be devel-

[2] In particular, the report does not discuss how a siting process to implement deep borehole disposal might be structured.

oped even if the proposed repository at Yucca Mountain were to be constructed and begin operation. Thus, regardless of the outcome of the ongoing national discussion, this analysis can help inform all interested parties about how site selection has been carried out in this country and around the world and what lessons might reasonably be drawn from those past experiences.[3]

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 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 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* such as 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 in the United States do decide to launch a new search for a repository, many issues will have to be addressed. 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.

[3] This report builds on two previous Board studies (NWTRB 2009; NWTRB 2011). Additional detailed information about waste-management programs in 13 countries can be found in those documents.

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;
- Uncertainties (technical and otherwise) 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*.[4]

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 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 in parallel. However, the laws and regulations that structure 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 each of the ten countries that have

[4] The siting effort in Finland is the exception to this statement. The Finnish radioactive waste-management program has moved forward for over 40 years without any serious interruption.

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.

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 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.

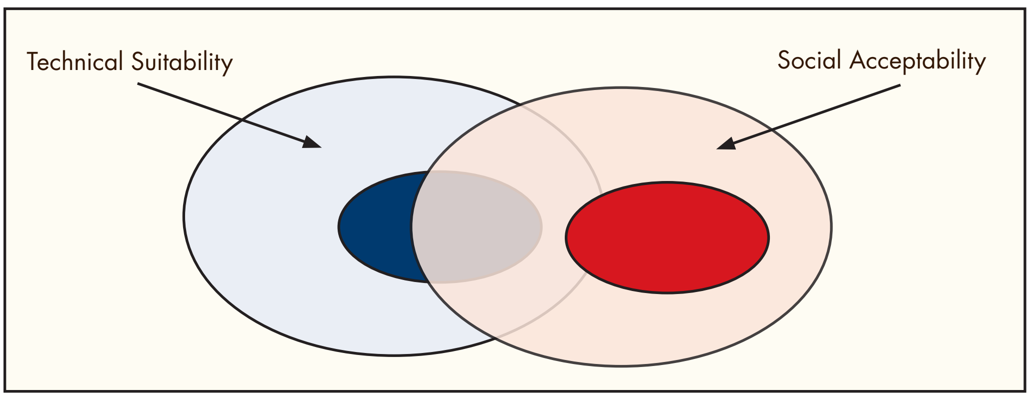

Figure 1. Selecting a site is an iterative process. It involves successive evaluations of technical suitability and social acceptability. Lighter shades denote early-stage judgments, and darker shades denote late-stage judgments.

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

If the implementer cannot identify sites that are both technically suitable and socially acceptable, it can either restart the siting process or modify the requirements for suitability and acceptability.

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 intricate and 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 political environment. To analyze the historical record in a way that allows meaningful comparisons to be made, some simplification of the siting process cannot be avoided. The simplifying framework used in this report has its origins in 1978, when President Jimmy Carter established the Interagency Review Group on Nuclear Waste Management (IRG) to develop an Administration-wide policy for managing radioactive waste.[5]

The IRG evaluated a wide range of strategies but concluded that the most promising one was, in fact, disposal of HLW and SNF in a deep-mined, geologic repository.[6] When it came to choosing a process for locating a site for such a facility, the IRG observed that selection involves passing possible geographic areas through two distinctly different "filters," one technical and one social.[7] On the one hand, detailed and often quantitative technical requirements have to be met. On the other, sites could be disqualified because of considerations such as "… lack of social acceptance, high population density, and difficulty of access." The Technical Suitability and the Social Acceptability Filters could be applied in any order. In the IRG's view at least, although the suite of locations eventually selected might be different, depending on the order in which the filters were applied, "… equally suitable sites should emerge from either approach …" (IRG 1978:80, 81). (Indeed, sometimes the order shifts as the process moves from one stage to the next.) At each stage of the siting process, when implementers, the political estate, and interested and affected parties make the specific and often legally mandated determinations, sites metaphorically "pass through" a filter. As the IRG recognized, the order in which they do so will vary from nation to nation. But what is unavoidable is the necessity to ultimately pass the proposed sites through both the Technical Suitability *and* Social Acceptability Filters. See Figure 2 on page 14.

This representation of the siting process, it should be noted, reflects well the legal and regulatory frameworks that have been enacted in all of the countries covered in this report: passage through one filter is *temporally separated* (at least formally) from passage through the other.[8]

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[5] The IRG included representatives from 14 federal agencies. Dr. Frank Press, President Carter's Science Advisor, and Dr. John Deutch, Director of the Office of Energy Research at DOE, were appointed as co-chairs for the group.

[6] The IRG considered partitioning and transmutation of the waste, shooting the waste into space, disposing of the waste in the seabed, burying the waste in the Antarctic ice sheet, and placing the waste in deep boreholes. DOE officially adopted the strategy of disposing HLW and SNF in a deep-mined, geologic repository in 1980 with the publication of a Final Generic Environmental Impact Statement (DOE 1980a). Congress ratified the choice of this strategy in the NWPA (U.S. Congress 1982). Since that time, systematic evaluations of potential long-term management strategies have been carried out in Canada, France, and the United Kingdom. All have reached the same conclusion in favor of geologic disposal.

[7] The Board first adopted this formulation in NWTRB 2011:35-47.

[8] The site-selection processes considered in this report are illustrated in Appendix 1.

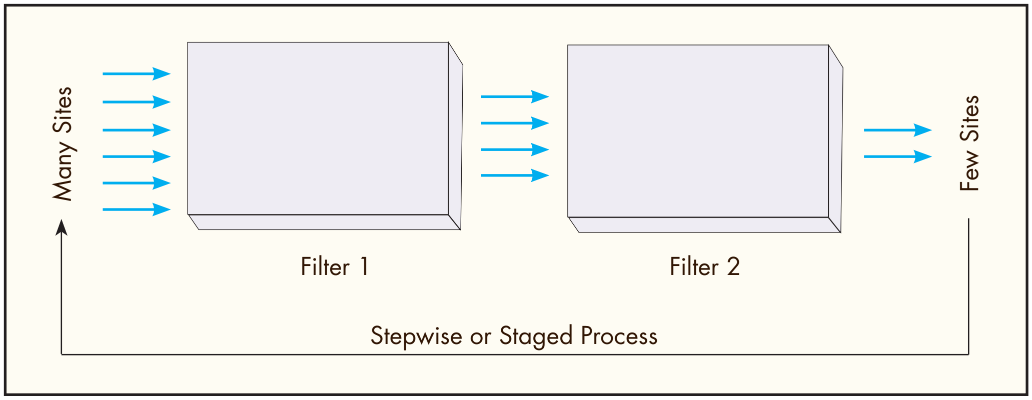

Figure 2. A simplified interpretation of the siting process. Possible locations must pass through both a Technical Suitability Filter and a Social Acceptability Filter to be selected as a site for a deep-mined, geologic repository.

The implementer winnows a large number of prospective settings down to a smaller number of potential sites. These are further reduced to several candidate sites.

At each stage in the siting process, then, the implementer, the political estate, and interested and affected parties winnow down the number of sites that remain in contention. Prospective settings (either areas or sites) are typically considered at the first stage in the process. Each actor renders very preliminary, often cursory, judgments on whether the settings might be suitable or acceptable for the development of a repository. In some cases, more than 200 settings have been appraised. These prospective settings are then further narrowed, both technically and socially; the sites passing this second stage emerge as potential sites. These locations undergo more systematic assessment so that a plausible argument might be made about their suitability and acceptability. Candidate sites are locations that have undergone extensive evaluation in the third stage to the point that they can be compared and a choice made.[9]

[9] It is conceivable that only one potential site will be considered. In that case, its passage through both filters will essentially be a "go-no go" exercise. Regardless of how many sites emerge from the process, however, additional steps must be taken before any location can be developed as a deep-mined, geologic repository. Those steps, which are inherently governmental and regulatory, and thus highly country specific, are beyond the scope of this report.

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.[10] A short description of each of these cases is provided in Table 1 on the following pages.[11]

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.

[10] All the initiatives but one involve attempts to site a deep-mined, geologic repository for HLW and SNF. The exception is the siting of the Waste Isolation Pilot Plant (WIPP), which currently can accept only transuranic waste originating in the U.S. nuclear defense complex. The inclusion of WIPP is dictated by the fact that it is the only operating deep-mined, geologic repository.

[11] For the reader interested in the history of repository siting in only a few of the ten nations considered in this report, headings in the so-called scholar's margins can be used to find where those nations are discussed. In addition, timelines for the siting activities that took place in the ten countries are included in Appendix 2.

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 National Academy of Sciences (NAS) first advanced the idea.[12] 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, depending on the particular disposal concept. A repository would probably look something like Figure 3 on page 20.

The implementer's objective in selecting a site and designing the facility is to delay and then limit the radionuclides in HLW and SNF that reach the accessible environment, mainly through transport by groundwater. A wide range of rock types have been considered as host formations for a deep-mined, geologic repository. One early study identified evaporites, such as salt, anhydrite, and gypsum; other sedimentary deposits, such as clay, shale, limestone, and chalk; and metamorphic and igneous rocks, such as granite, gneiss, schist, basalt, and volcanic tuff, as potentially suitable geologic hosts (IAEA 1977). Notwithstanding this diversity, mature *disposal concepts* have been developed only for a repository constructed in salt, crystalline rock, clay/shale, and volcanic tuff formations. Each of those concepts posits different means for achieving waste isolation and containment. (See Box 2 on page 20 for more information about disposal concepts.)

The amount of flexibility a nation has in choosing a disposal concept depends as a very practical matter on how geologically heterogeneous it is. For example, in some countries

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[12] The concept traces back to a 1957 study. The focus then was on the disposal of liquid HLW. Although the study group noted that additional research was still needed, it concluded that "radioactive waste could be disposed of safely in a variety of ways and in a number of sites in the United States" (NAS 1957:16). In 1968, the Atomic Energy Commission (AEC) promulgated a regulation that required the solidification of the liquid HLW within five years of its production at a reprocessing plant (AEC 1968). This report focuses solely on the disposal of solidified (vitrified) HLW as well as SNF.

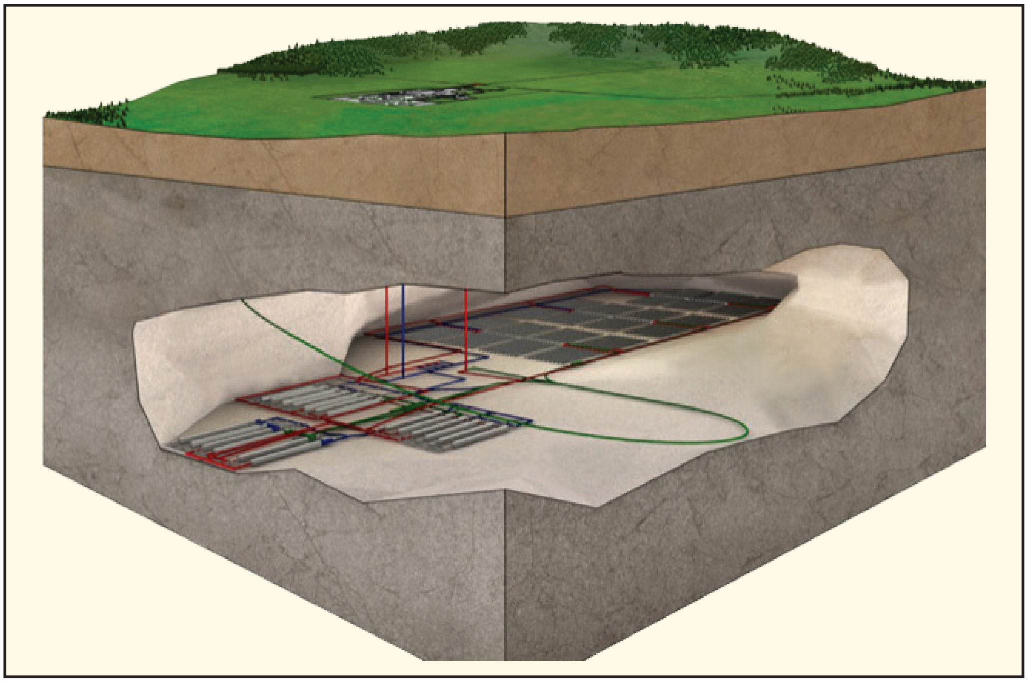

Figure 3. Layout of a generic deep-mined, geologic repository. The black lines represent drifts where the waste will be emplaced; the green, blue, and red lines are shafts and ramps. (Source: Nuclear-News Net 2013)

The 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

such as Sweden and Finland, bedrock granite and gneiss underlie virtually the entire country. In Belgium and Switzerland, the only practical option seems to be a repository built in some variety of clay-rich rock or sediment. Other countries, such as Canada, China, France, Germany, and Japan, conceivably could construct a repository in at least two different host-rock formations.

Because it has significant occurrences of the rock types that have been considered for hosting a repository, the United States has more flexibility than most nations when it comes to selecting a disposal concept. DOE has invested significant resources in characterizing (investigating) the volcanic tuff at Yucca Mountain (DOE 2008). It is now building on the work carried out abroad on disposal concepts that envision a repository constructed in salt, crystalline rock, and clay/shale formations (DOE 2011).

A Disposal Concept for Salt Host-Rock Formations

For more than one-half of a century, disposal of HLW and SNF in salt has been explored in detail in several countries, but especially in Germany and the United States. Indeed, when the NAS panel first proposed developing a repository, its leading host-rock candidate was salt formations (NAS 1957:4-5 and Appendix F).[13]

As originally articulated, the salt disposal concept appears elegant in its simplicity: if the salt is there, water flow, the predominant mechanism for transporting waste to the biosphere, is probably not occurring at rates of concern for waste disposal. It is then just a matter of finding a large enough and properly placed formation, inside of which drifts would be carved. Waste would be lowered and emplaced into the drifts, perhaps in boreholes or on the drift floor.[14] The shafts leading to the repository, the drifts themselves, and the boreholes would then be sealed with crushed and compacted salt.

Under lithostatic pressure, the salt would flow slowly, closing around emplaced disposal packages and healing any fractures or voids that may have formed during the repository construction phase. Waste packages are not considered long-term barriers for isolating and containing HLW and SNF in salt environments because localized brine inclusions can cause them to fail. Even so, since the environment in the immediate vicinity of the emplaced waste will evolve over several hundred years from oxidizing conditions to its natural reducing condition, the radionuclides in the waste will remain in a relatively insoluble form.

This description of the salt disposal concept disregards some critical issues. Salt formations can contain sedimentary layers, such as thin beds of clay, which can release water and also possibly undermine a formation's structural integrity. Under the influence of heat, brine inclusions can migrate and possibly create pathways that challenge waste isolation and containment.

Nonetheless, generic (non-site-specific) analyses have been carried out to evaluate how well a deep-mined, geologic repository in salt might isolate and contain HLW and SNF. Those generic studies address a range of questions, including the effect of heat on brine migration and whether pressures become too great when hydrogen is generated should small amounts of water contact the waste. The results stemming from site-specific modeling work support the proposition that an undisturbed salt repository holding non-heat-generating waste will maintain its integrity for long periods of time (EPA 1998). Additional modeling based on a potential site in Germany appears to support the proposition for heat-generating waste as

[13] A very similar concept was used by DOE in developing WIPP in New Mexico.

[14] Thermal limits would probably have to be set for any HLW and SNF disposed of in a salt repository.

well, although that claim has not been subjected to a formal empirical or regulatory test.[15] But at least some participants in the German program believe that an undisturbed deep-mined, geologic repository in salt will have zero release to the biosphere of the constituents of heat-generating waste (radionuclides) for at least one million years (Krone et al. 2008).

The operative word here of course is "undisturbed."[16] Human intrusion is especially a concern for the salt disposal concept because salt deposits often occur in association with extractable resources, such as potassium, oil, and natural gas. Future exploration for these valuable resources may lead to drilling that could intersect the geologic repository, thereby creating fast and direct pathways that would allow the waste to migrate to the accessible environment. Indeed, for WIPP, a deep-mined, geologic repository for transuranic defense waste in New Mexico, the human intrusion scenario is responsible for the largest potential future radionuclide release (Westinghouse 1995).

A Disposal Concept for Crystalline Host-Rock Formations

Originally proposed in 1977 and modified twice over the next five years, a disposal concept for a repository located in Sweden's granitic basement rock was advanced by the utility-owned Swedish Nuclear Fuel and Waste Management Company (SKB) (SKB 1983). The so-called KBS-3 concept also has been adopted by Finland, and variants are under consideration in Canada, China, and Japan.

Crystalline rocks, such as granites and gneiss, are not impermeable; fractures permit groundwater to flow within a typical formation. The foundational premise of the KBS-3 concept, however, is that a repository can be sited in an anoxic environment where the specific chemical (slightly basic pH) and electrochemical (reducing) properties of the groundwater are such that objects made of elemental copper resist corrosion (SKB 2006). Taking advantage of this insight, SKB intends to place the SNF in five-centimeter-thick canisters fabricated out of that material. Within the copper canister is a nodular cast-iron insert, which is designed to increase the mechanical strength of the waste package (Hedin 2008). The chemical and electrochemical conditions also greatly enhance the durability of the UO_2 in the SNF, making the waste form, as well as the canister, a significant barrier to the release of radionuclides.

Rings of bentonite clay and sand would be used to line the boreholes where the packages are emplaced.[17] This material would limit the exposure of the copper canisters to groundwater, filter colloids that might be generated from the corrosion of the SNF and its cladding, protect the canisters in the event of small movements in the rock, and delay the spread of radionuclides that might escape from the waste package. The repository would be designed so that the drifts also can be backfilled with bentonite.

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[15] Beginning in 2005, a joint project sponsored by the German Ministry of the Economics and Technology (BMWi) and the Ministry of the Environment, Nature Conservation, and Nuclear Safety (BMU) assessed the salt disposal concept using the full catalog of features, events, and processes; appropriate scenarios; and numerical analyses. Eventually, the project used site-specific information gathered at the Gorleben site to perform the evaluation. In 2012, however, "the project objectives were modified in such a way that no suitability statement for the Gorleben site would have to be given …" (Bollingerfehr et al. 2013:11).

[16] "Undisturbed" in this context means that inadvertent intrusion has not breached the host-rock formation down to the repository level.

[17] Because bentonite degrades at elevated temperatures, thermal limits would probably have to be set for the disposal of HLW and SNF in a crystalline rock repository. Most evaluations suggest that the bentonite would have to be kept below 125° C.

Finally, the crystalline host rock provides two additional barriers: matrix diffusion traps radionuclides in the "dead ends" of the microfracture system and the surfaces of minerals sorb radionuclides, particularly actinides.

Figure 4 portrays the elements of the KBS-3 disposal concept.

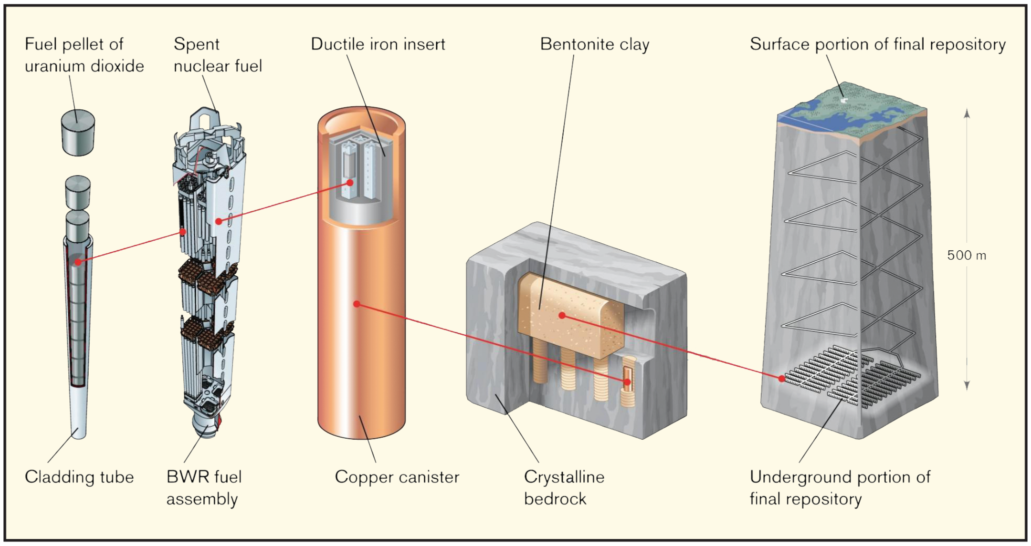

Figure 4. The KBS-3 method. It involves encapsulating the SNF in copper canisters that are then emplaced, surrounded by a buffer of bentonite clay, in deposition holes in a tunnel system at a depth of 400-700 meters in the bedrock. (Source: SKB 2011b)

In SKB's view, this system of multiple compatible natural and engineered barriers limits sharply any release of radionuclides into the environment. That assessment has been endorsed in several international peer reviews (NEA 2000; NEA 2012). Nonetheless, the implementer's claims about copper corrosion in anoxic environments have been challenged by researchers, notably from Stockholm's Royal Institute of Technology (Szakálos et al. 2007; Swedish National Council 2014b), and its claims about the stability of the bentonite rings have been questioned by the Swedish National Council for Nuclear Waste (Swedish National Council 2013).[18]

A Disposal Concept for Clay/Shale Host-Rock Formations

A repository mined from a formation of clay sediments or clay-rich rocks (mudstones, claystones, argillite, shale) may be an effective approach to isolating and containing HLW and SNF.[19] Three countries are actively investigating the possibility of developing a deep-mined, geologic repository in clay formations found within their borders: Belgium (Boom and Ypresian clays), France (Callovo-Oxfordian argillite), and Switzerland (Opalinus clay). In addition, Canada, China, and Japan have kept open the possibility of developing a repository in clay. Although some important differences exist among the countries' disposal concepts and the types of waste they will dispose of, the similarities in the concepts

[18] In a February 11, 2015, statement to the Finnish Ministry of Employment and the Economy, the Radiation and Nuclear Safety Authority, STUK, concluded that the SNF encapsulation plant and final disposal facility designed by Posiva Oy based on the KBS-3 concept can be built to be safe.

[19] This report shall use the term "clay" generically to refer to clay sediments and clay-rich rocks.

are more substantial.[20] For the purposes of the discussion below, Switzerland's national program serves as an illustrative example.

Like salt, clay is ductile, so fractures at depth seal over time. Consequently, advective groundwater flow in the clay host rock is very limited, meaning that the waste form and the steel waste package are likely to remain intact for at least several thousands of years.[21] Once released, the radionuclides would have to travel first through the bentonite clay, which backfills all the drifts, and subsequently into the undisturbed host rock, which maintains reducing conditions in an anoxic environment. The radionuclides would move at a very slow rate, controlled by diffusion. Some of the radionuclides would be sorbed on the Opalinus clay, preventing any further movement.

Thus, in the view of the Swiss implementer—the public-private consortium, National Cooperative for Disposal of Radioactive Waste (Nagra)—many hundreds of thousands of years after the waste has been emplaced, only the most mobile and longest-lived radionuclides would have reached the edge of the host-rock formation. Exogenous events, such as significant climate change, borehole penetration of the repository, and deep groundwater extraction at the site, trigger the only scenarios that are likely to result in any radionuclide release to the biosphere (Nagra 2002a). An international peer review supported the major pillars of the Swiss safety case (NEA 2004).

A Disposal Concept for Volcanic Tuff Host-Rock Formations

The United States is the only country that has considered disposing of HLW and SNF in a deep-mined, geologic repository located in the volcanic tuff found in the unsaturated zone (above the water table) at a specific site, Yucca Mountain, Nevada. Initially, the disposal concept took advantage of the fact that very little precipitation falls on the site. A large fraction of what does fall returns to the environment by evaporation, plant transpiration, and runoff; only a small amount of water infiltrates below the root zone and even less seeps into the repository drifts. Calling the site "dry," DOE maintained that radionuclide transport to the accessible environment would be minimal. Consequently, up until the mid-1990s, DOE saw little need to employ robust waste packages. (For a critique of that position, see NWTRB 1992.)

Because some investigations carried out at that time suggested that seepage into the drifts might be significantly greater than originally anticipated, the disposal concept was modified (DOE 1998).[22] The new concept now rested on two main supports. First, engineered barriers would minimize the amount of water that could come in contact with the HLW and SNF. Second, transport of radionuclides to the biosphere would be limited by the amount of water leaving the drifts (Abraham 2002:20-23).

The location of the proposed repository lies in an oxidizing environment, where constituents of SNF, mainly UO_2, would react with oxygen and become more mobile. To limit the release of radionuclides, corrosion-resistant titanium drip shields would be installed to

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[20] France is the only country planning to dispose of the vast majority of its high-activity radioactive waste as HLW embedded in a glass waste form. Consequently, it has conducted extensive research on how this waste form will interact with argillite over millennia.

[21] Because the clay and bentonite degrade at elevated temperatures, thermal limits would probably have to be set for the disposal of HLW and SNF in a repository constructed in clay host rock.

[22] For a discussion of the bureaucratic activity surrounding that shift, see Metlay 2000.

divert the water that enters the drifts, protecting the waste packages that rest underneath. The packages themselves would be fabricated with an outer layer of a nickel-based, corrosion-resistant material, Alloy 22, and an inner layer of stainless steel. According to DOE, the packages will degrade very slowly in the environment of the proposed repository. The revised volcanic tuff disposal concept for Yucca Mountain is illustrated in Figure 5.

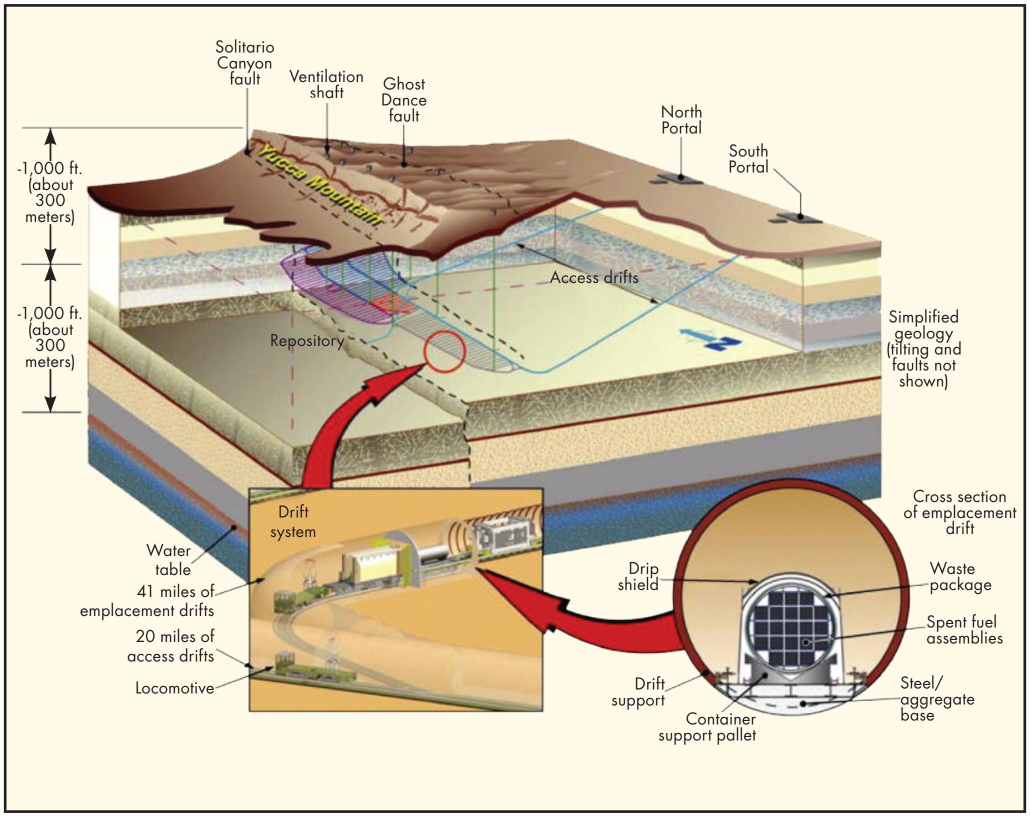

Figure 5. The disposal concept adopted for the proposed Yucca Mountain repository (Source: DOE 2008)

As with the other disposal concepts, questions remain about the performance of the proposed repository. The NWTRB, for instance, has noted that there is only a poor understanding of how fast water moves in the unsaturated zone (NWTRB 2008:30-31). It also has suggested that deliquescence-induced localized corrosion could lead to more rapid waste package degradation than DOE assumes (NWTRB 2008:25-28).[23] Nearly 300 issues have been raised collectively by supporters and opponents participating in the licensing hearing convened by NRC. These contested issues might eventually be resolved in the course of such a proceeding. For the moment, however, that inquiry has been suspended.[24]

Table 2 on the following page summarizes the characteristics of the four disposal concepts that have been investigated in the United States and elsewhere. The table makes clear that the performance of a repository system 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

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[23] This type of corrosion is caused by the absorption of atmospheric water vapor by a solid salt to the point that the salt dissolves into a corrosive saturated solution.

[24] In January 2015, NRC staff released the last of its five-volume *Safety Evaluation Reports* on Yucca Mountain. It concluded that DOE's license application demonstrated compliance with all relevant safety, environmental, and security regulations (NRC 2015).

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

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 of, for example, a salt and a clay formation? As will be discussed later in this report, 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.

In April 2014, DOE issued a report evaluating different rock types as options for the permanent disposal of HLW and SNF. These included the salt, crystalline rock, and clay/shale disposal concepts as well as deep borehole disposal.[25] The analysis concluded that all of the options considered were viable strategies for the long-term management of HLW and SNF.[26] In particular, the report maintained that, with the possible exception of a small amount of DOE-owned SNF, deep-mined, geologic repositories grounded in the three disposal concepts "could be designed, constructed, and operated to provide safe and robust isolation of the [existing] waste forms" (DOE 2014a:xvii).

DOE's evaluation focused on only generic options. Its conclusions do not go much beyond recapitulating what has been learned over the past 30 years in the United States and abroad. By design, DOE's report does not address a critically important question: how do you identify *specific sites* where an implementer has confidence that a proposed repository can satisfy both the technical and social requirements? This report is intended to provide information to policymakers about how that gap was addressed historically, and how, in the United States, it might be filled in the future.

[25] A discussion of the disposal concept for volcanic tuff host-rock formations was not included.

[26] It seems to suggest, however, that deep borehole disposal was only technically feasible for specialized waste forms that could be placed in small packages.

Technical Suitability Filters

Because the projected postclosure performance of a deep-mined, geologic repository will be highly dependent on where it is located, technical suitability is the *sine qua non* for the choice of any particular repository site.[27] But hypothetically promising locations, however, are not equally suitable, whether in terms of performance margins or confidence levels. Consequently, there are often calls from interested and affected parties to find the "optimal" or "best" site. Yet the workability of seeking ever-better sites is quite problematic: it is impossible to look everywhere and to compare an unlimited number of possible locations. So almost by default, national waste-management programs have either explicitly or implicitly adopted a common approach, which was articulated by the International Atomic Energy Agency (IAEA): "It is not essential to locate the *best possible site*, but to provide an overall disposal system that can be *convincingly* shown to comply with safety and environmental protection requirements [emphasis added]" (IAEA 1994:3). What follows describes how the Technical Suitability Filter is constructed and applied.

Using the Technical Suitability Filter to Identify Prospective Settings and Potential Sites

Implementers design Technical Suitability Filters to differentiate among 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 (see, for instance, ORNL 1972; TVO 1982; and SKB 1989).

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[27] This report focuses almost exclusively on siting considerations that directly affect a repository's post-closure performance. Undeniably, characteristics of a site may also affect a repository's preclosure or operational performance.

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 applies Generic Criteria to screen and compare potential sites found in different host rocks. (For examples of proposed Generic Criteria, see IAEA 1977, 1994, 2011; NAS 1978; CEC 1980; NEA 1981; DOE 1984c; and AkEnd 2002.)

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.[28] 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 (NUMO 2002a; DEFRA 2008b; and NWMO 2010). As the process moves forward, potential sites are evaluated against increasingly more detailed and exacting technical criteria (see, for instance, NWMO 2013).

Box 3 elaborates on the differences among the three types of site-suitability criteria.

[28] The "permeability" of these Exclusion Criteria is likely attributable to two complementary considerations: 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

Table 3 on page 32 records the Exclusion Criteria that have been explicitly adopted by several countries discussed in this report. Tectonic activity, that is, the potential for active earthquakes or folding, 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 prospective settings from consideration at the start. For example, in Canada, of the 22 communities that expressed an 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.

Regardless of how Technical Suitability Filters are designed, they seem to eliminate relatively few sites from consideration at the start. In most countries, repositories can be constructed in many locations.

Condition	Canada	France	Japan	Sweden	Switzerland	United States*	United Kingdom
Fast and/or significant ground-water flow	■	■		■		■	
Unfavorable ground-water 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

The following subdivisions of this report consider how Technical Suitability Filters were applied in the early stage of each of the 24 siting efforts. The subdivisions are organized first by the type of site-suitability criteria, then by disposal concept, and then by country.[29]

Host-Rock-Specific Criteria (Single Disposal Concept)

United States

Because of a country's underlying geology or land-use restrictions, some national waste-management programs reach at least a tentative conclusion early on about the choice of disposal concept. Then, searches for prospective settings and potential sites are guided by the Host-Rock-Specific Criteria that influence the capability of that particular disposal strategy to isolate and contain HLW and SNF.

Disposal Concept for Salt Host-Rock Formations

For more than 15 years, the 1957 NAS report had a profound effect on the strategy of the waste-management program in the United States. A series of studies, experiments, and one abandoned siting effort were all directed at developing a deep-mined, geologic repository

[29] The discussions of Host-Rock-Specific Criteria and Generic Criteria also include a description of how the implementer applied Exclusion Criteria. The discussion of Exclusion Criteria is limited to those instances where the implementer provided guidance to communities interested in possibly volunteering to host a repository.

for HLW in a salt formation (see, for instance, Geotechnical Corporation 1958; Pierce and Rich 1962; Bradshaw et al. 1969; and AEC 1971a).[30] As Figure 6 depicts, the focus on salt is not unexpected, given the widespread domestic presence of salt formations.

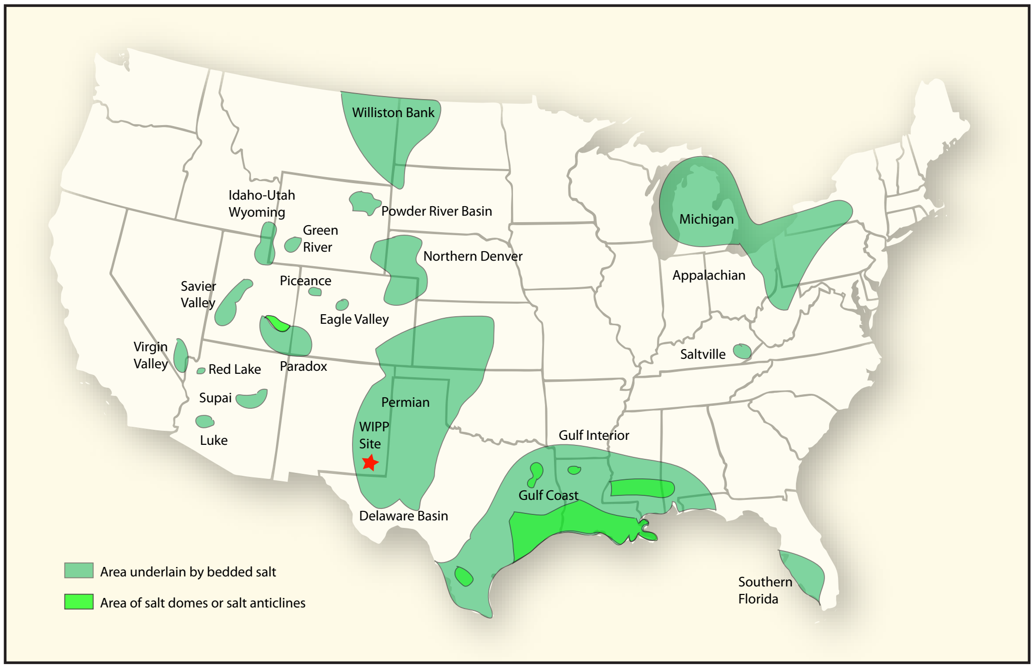

Figure 6. Distribution of salt formations in the United States (Based on Lomenick 1996)

Initially, the siting criteria were quite general, requiring only a sufficient volume of rock, impermeable enclosing beds, and suitable purity (Lomenick 1996:9). Once the Atomic Energy Commission (AEC) decided to develop a demonstration repository, these general requirements became more specific and new ones were added.

The AEC's Oak Ridge National Laboratory (ORNL), the Kansas Geological Survey (KGS), and the University of Kansas all suggested Host-Rock-Specific Criteria. Typically, the bedded salt host rock had to be (1) approximately horizontal, relatively undisturbed structurally, at least tens of kilometers in areal extent, and located no less than 150 meters but no more than 600 meters below the surface; (2) tectonically stable; (3) relatively pure; and (4) away from potentially valuable reserves of petroleum or other mineral resources (see, for example, Culler 1971). Based on available data, prospective settings along the Gulf Coastal Plain; in Utah and Colorado (Paradox Basin); in New Mexico, Texas, and Kansas (Permian Basin); and in Michigan, Ohio, Pennsylvania, and New York (Salina Group) were evaluated. As this report discusses below, the AEC's attention soon focused on potential sites in central Kansas and on one site in particular located near the small town of Lyons.

Germany

Buttressed as well by the publication of the NAS study, the German Federal Institute of Soil Research in 1963 prepared a report enumerating the reasons why salt formations were particularly suitable host rocks for a deep-mined, geologic repository and proposed six

[30] For a well-scrubbed early history of the siting process in the United States, see Lomenick 1996. A more nuanced, albeit less comprehensive, analysis can be found in Carter 1987 and Vandenbosch and Vandenbosch 2007.

geotechnical site-suitability criteria.[31] These criteria generally pointed to the same geological features that were being considered in the United States. The Federal Ministry of Research and Technology then asked the Federal Institute to identify potential sites for a facility. Seven salt beds and domes (all but one in the *Land* [State] of Lower Saxony) were proposed. Sites at Krummendeich and Bunde/Jemgum were considered "particularly suitable."[32] The site at Leutesheim was given a negative ranking on account of the relatively high seismic hazard in the area. Field investigations began in 1965 at the two favored sites but were terminated a year later.

In 1973, however, the German government launched an initiative to create a nuclear waste-management center, consisting of a commercial reprocessing plant, a centralized vitrified HLW storage facility, and a deep-mined, geologic repository. The Federal Ministry for Research and Technology commissioned the private Nuclear Fuel Reprocessing Company (KEWA) to evaluate potential sites. Suitability for a repository was only one out of 11 criteria considered. KEWA recommended ten potential sites, but none of those proposed by the Federal Institute for a repository were included. The sites, again all but one in Lower Saxony, were chosen mostly on the basis of land-use planning and nature conservation. Three of them (salt domes at Wahn, Lutterloh, and Lichtenhorst) appeared particularly promising.[33]

By 1976, this process had bogged down largely due to local opposition, prompting the Lower Saxony government to ask the central government to suspend its efforts until the *Land* could designate a site on its own. The Lower Saxony government then began a four-phased evaluation that initially considered 140 prospective settings. Fifteen parameters, including six heavily weighted geotechnical ones, were first used to assess different salt domes.[34] Potential sites at Wahn and Lichtenhorst survived this winnowing process, as did a salt dome at Höfer and another one at Gorleben. As this report describes below, Gorleben eventually emerged as the presumptive choice. Figure 7 shows the six potential sites considered in Lower Saxony and one in Schleswig-Holstein.

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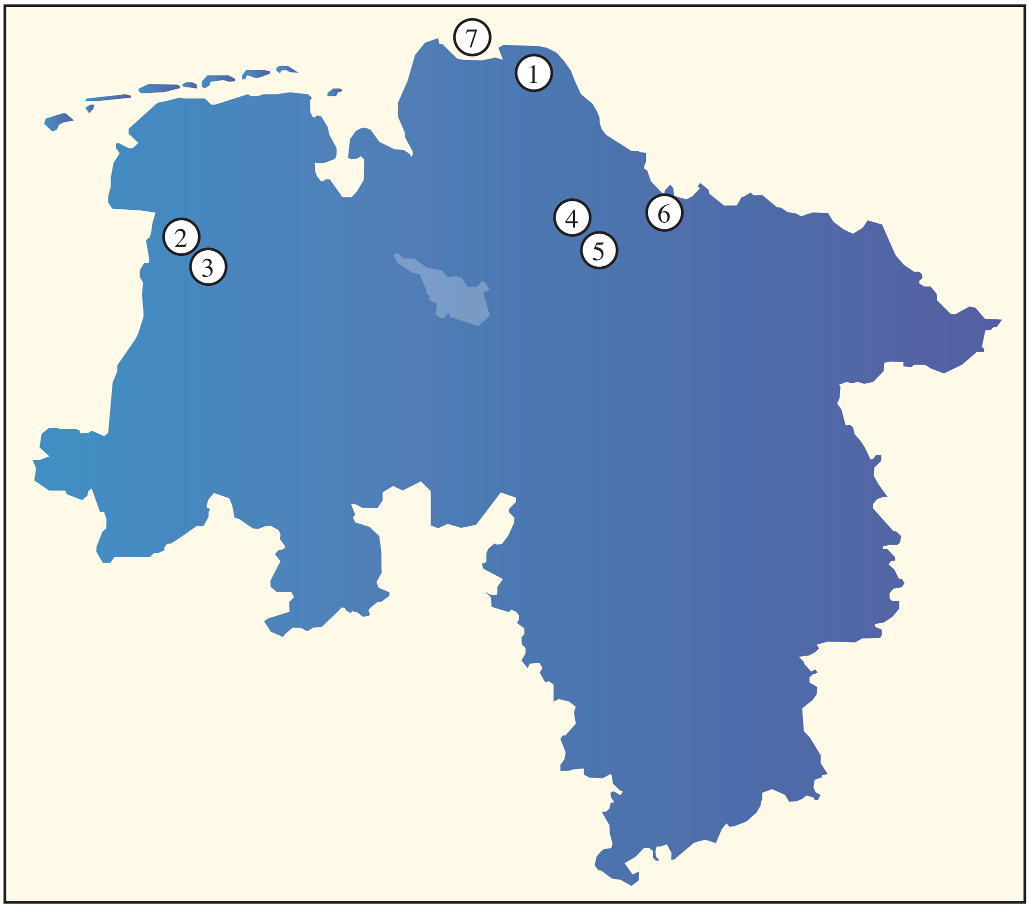
[31] The source material supporting this description of the early efforts to develop siting criteria for a repository in salt is available only in German. Consequently, what follows relies mostly on BMWi 2008.

[32] Starting in 1964, additional support for the salt disposal concept emerged from tests conducted at the Asse II underground research laboratory in Lower Saxony. Although the waste type studied at Asse was low- and intermediate-level (including some plutonium), not HLW and SNF, the German government appeared comfortable extrapolating the results for non-heat-generating waste types to heat-generating types.

[33] A salt dome at Lütau, although technically promising, was dropped from consideration because its location was too close to the border of the former German Democratic Republic.

[34] A complete listing of these parameters, based on BMWi 2008:51, is provided in Appendix 3.



1. Krummendeich 3. Wahn 5. Höfer 7. Lichtenhorst*
2. Bunde/Jemgum 4. Lutterloh 6. Gorleben *Lichtenhorst is in Schleswig-Holstein.

Figure 7. Location of potential sites in Lower Saxony and Schleswig-Holstein (Based on BMWi 2008)

Disposal Concept for Crystalline Host-Rock Formations

Sweden

In 1977, the Swedish Parliament passed the Nuclear Power Stipulation Act.[35] Among other things, the law required owners of the six nuclear power plants then under construction or whose fuel had not yet been loaded to show *how* and *where* those reactors' HLW and SNF could be disposed in order to guarantee *absolute safety*. Lacking significant salt beds or domes, SKB was charged with finding the "best granitic bedrock." Within a few months, it developed an approach that culminated in the adoption of the KBS-3 disposal concept.

If the concept allowed SKB to address the Stipulation Act's "how" requirement, satisfying the "where" requirement was not nearly as straightforward. In October 1978, the Swedish government rejected an application to fuel the Ringhals 3 reactor because SKB had failed to identify a *specific site* for the repository. However, it left open the possibility that SKB could conduct supplemental geologic studies to demonstrate whether "*there exists* a sufficiently large rock formation at the required depth and with qualities that the [SKB] safety analysis … gives as necessary prerequisites [emphasis added]" (quoted in Sundqvist 2002:87). Data from investigations into the bedrock near the town of Sternö on the southeast coast were included in an amended application.

[35] This law was replaced by the Nuclear Activities Act in 1984.

From the review of that submission arose the first *de facto* siting criteria in Sweden. In 1978, the regulatory authority, then the Swedish Nuclear Power Inspectorate (SKI), convened an advisory committee and asked it to determine whether the Host-Rock-Specific Criteria influencing the viability of the KBS-3 disposal concept had been satisfied at the nominal site:

- Degree of seismic activity
- Frequency of faults and crush zones
- Sufficient depth to avoid large-scale erosion effects during periods of glaciation
- Composition of groundwater
- Density of rock
- Transportation time for the groundwater
- Absence of valuable and exploitable minerals

Although SKI specified some of the parameters only qualitatively, it did observe that SKB had already concluded that others, such as the pH and transport time for the groundwater, had to fall within a restricted range (SKB 1977; also see Sundqvist 2002:89-90).

The committee vigorously debated whether the Sternö data were adequate to demonstrate whether the "where" requirement in the Stipulation Act could be met, at least in principle. SKI, however, adopted a different line of reasoning in explaining its decision to approve the fueling of Ringhals 3 in 1979. It embraced a system perspective, arguing that the natural barrier could not be evaluated independently of the engineered barrier. "The importance of the requirements on the geological barrier [should] not be exaggerated, and the long-term processes in the rock are not that important anyway, as long as the other barriers are good" (quoted in Sundqvist 2002:91). In effect, instead of requiring SKB to find the "best bedrock," SKI gave the implementer wide latitude to select a site for a repository as long as the rock was suitable enough.

Having cleared the pressing hurdles set in place by the Stipulation Act, SKB began a series of site investigations designed to collect a broad body of geoscientific data in bedrock of differing types, ages, and deformation. Between 1977 and 1985, boreholes were drilled and logged. "Particular emphasis was placed on determining the hydraulic permeability and the chemical composition of deep groundwater" (SKB 2011a:122). The locations of what many parties believed to be prospective settings are shown in Figure 8 (Elam and Sundqvist 2009:978-979).

During that period, SKB rejected advice from several government oversight bodies that recommended a systematic winnowing exercise to identify sites that might be suitable.[36] Instead, it relied on and amplified SKI's system perspective and made explicit the perspective's primary message. As one report to the Swedish government noted, "There are many sites in Sweden that meet the requirements that can be made on the geology at a final repository. The only prerequisites are low groundwater flow and favorable groundwater chemistry" (SKB 1989:67-68).

After local opposition forced those early studies to end before any final determinations could be made, the system perspective led SKB to reevaluate its siting approach and to ask municipalities to permit feasibility studies. These studies would eventually identify a set of potential sites. Figure 9 indicates where this second round of investigations was carried out.[37]

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[36] For a detailed discussion of the back-and-forth between SKB and its overseers on the need for more specific site-suitability criteria, see Sundqvist 2002:113-125.

[37] Oskarshamn, Östhammar, and Nyköping host nuclear facilities.

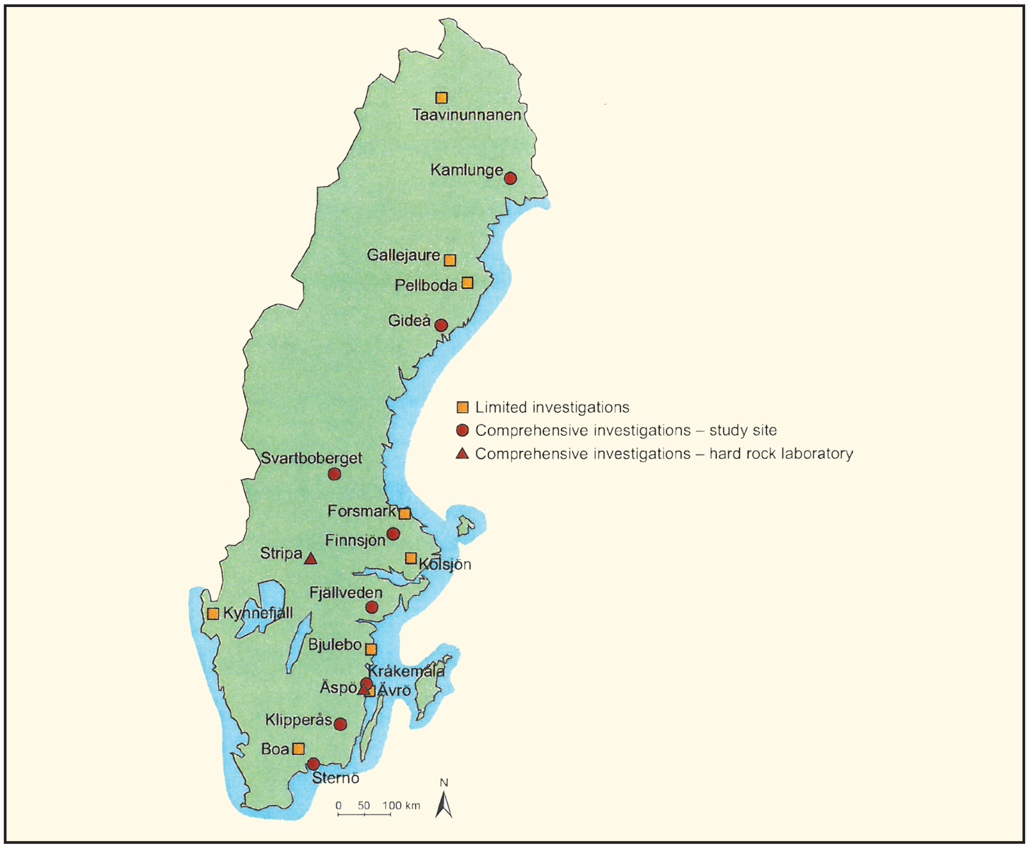

Figure 8. Prospective settings in Sweden (Source: SKB 2011a)

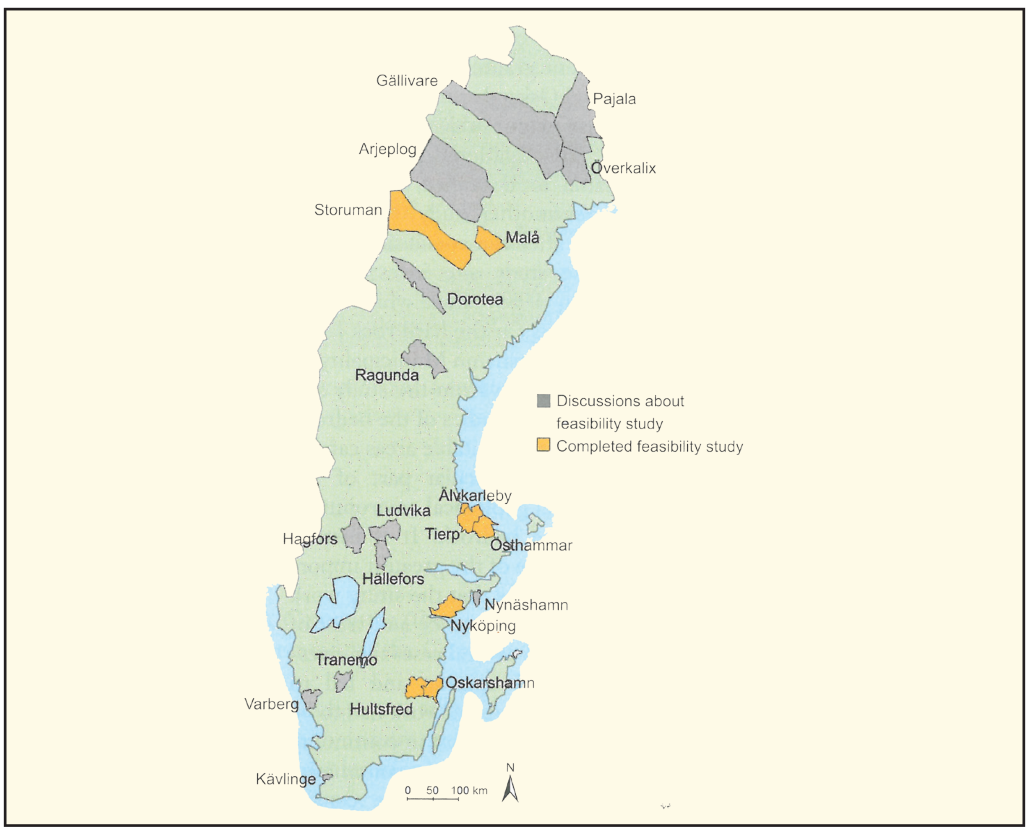

Figure 9. Potential sites in Sweden (Source: SKB 2011b)

Finland

The Finnish implementer—a utility-owned corporation, Posiva Oy—chose to adopt the KBS-3 disposal concept and its underlying system perspective.[38] Although the gneiss that dominates in Finnish bedrock differs slightly from the granitic bedrock in neighboring Sweden, the fundamental conditions are sufficiently similar in the two countries that the concept still appears to be fully applicable (Posiva Oy 1999b).

The Finnish effort initially advanced at a slightly slower pace than the Swedish one. Between 1982 and 1985, studies classifying the rock mass in Finland and the parameters that influenced its suitability for disposal purposes were published (Ninni et al. 1982; Vuorela and Hakkarainen 1982).[39] In addition to the parameters noted by SKI, these two analyses pointed to formation size, homogeneity, and sorption as critical variables. Groundwater flow, but not groundwater chemistry, was considered in a third study (Salmi 1985).

Site-identification surveys, which considered 327 target areas, led Posiva Oy to propose to its regulator, the Radiation and Nuclear Safety Authority (STUK), and to the Ministry of the Environment, that 102 prospective settings should be more intensively investigated.[40] The authorities eliminated 16 areas and, after discussions with the affected communities and evaluations of geologic factors, decided on five potential sites in 1987. In 1997, after the SNF from the Loviisa reactors could no longer be repatriated to Russia, Posiva Oy added the site at Hästholmen, where those reactors are located, to the mix. Figure 10 shows the location of the six potential sites.

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[38] Two utilities, TVO and IVO (Fortum after 1999), each own two operating reactors in Finland. IVO's Loviisa reactors are Soviet-built and are located in Hästholmen; TVO's Olkiluoto reactors are designed by Westinghouse and are located in Eurajoki. IVO's contract included take-back of SNF and disposal of the reprocessed HLW in the Soviet Union. TVO, after unsuccessfully attempting to export its SNF, launched a waste-management program that focused on identifying a domestic repository site. A 1994 amendment to the Nuclear Energy Act prohibited both the import and export of HLW and SNF. The law halted the export of IVO's SNF to Russia and directly led to the formation of Posiva Oy in 1995, which is owned 60 percent by TVO and 40 percent by IVO. Importantly, Posiva Oy maintains that it has no responsibility for disposing of the SNF generated by Fennovoima, a new utility seeking to construct a nuclear power plant in northern Finland. The Finnish government has urged the two parties to negotiate, but as of May 2015, no agreement had been reached.

[39] The source material supporting this description of the early efforts to develop siting criteria for a repository in crystalline rock is only available in Finnish. Consequently, what follows relies on McEwen and Äikäs 2000:13-24.

[40] Although Finland's 1987 Nuclear Energy Act considers issues related to radioactive waste management in considerable detail, it does not contain guidance about selecting potential or candidate sites. The only disqualifying factors listed in STUK's 2001 regulatory guide, YVL 8.4 (3-3), state that "an area having a feature that is substantially adverse to long-term safety shall not be selected as a disposal site."

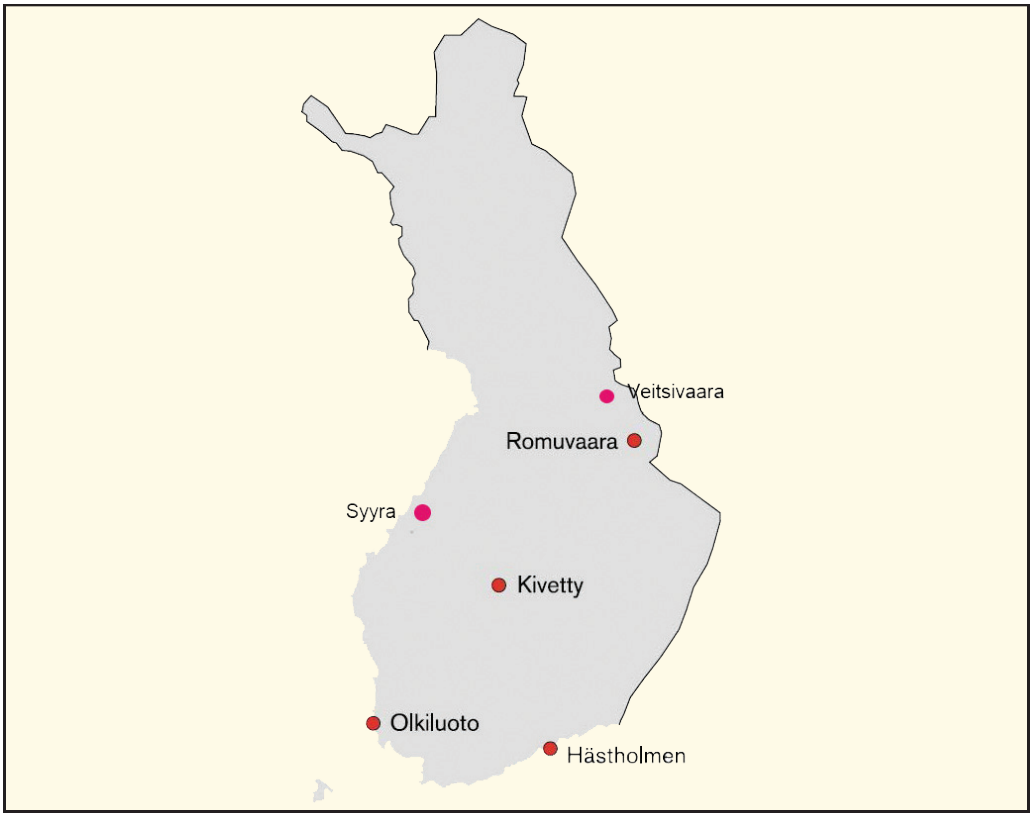

Figure 10. Potential sites in Finland (Source: Posiva Oy 1999b)

Disposal Concept for Clay/Shale Host-Rock Formations

Switzerland

In Switzerland, the initial focus of Nagra was on developing a deep-mined, geologic repository in granite (Nagra 1985).[41] In its 1988 review of the scientific and technical investigations, the Swiss Federal Council concluded that the concept's safety and engineering feasibility had been adequately demonstrated. But the Federal Council believed that it was not possible "to say with confidence that sufficiently large areas of crystalline rock with the required properties [tectonic stability and low faulting] could be found in Switzerland. … [T]hus, siting feasibility was not fully demonstrated" (cited in Nagra 2002a:7). (See Box 4 on page 40 for additional information about this decision.) The Federal Council then instructed Nagra to focus on sedimentary formations, most notably Opalinus clay and the Lower Freshwater Molasse (marly mudstones).

Over the next 14 years, Nagra intensively investigated a broad swath of northern Switzerland. Because formal guidelines or disqualifying factors had not yet been promulgated, Nagra structured its investigations through informal consultations with the regulatory authorities.[42] Publicly, Nagra articulated six siting "principles" (Nagra 2002a:36):

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[41] The Swiss disposal concept considered differed from the Swedish KBS-3 approach in that the canister would be made out of steel, not an outer layer of elemental copper.

[42] The Swiss government eventually did impose several requirements: (1) clay depth had to be 400-1,000 meters, (2) thickness had to be at least 100 meters, (3) bedding had to be tectonically undisturbed, and (4) there could be no indication of neotectonic activity. Only in 1999, however, did the regulatory authority publish formal criteria for demonstrating "siting feasibility." For the most part, it adopted Nagra's principles but added (1) low-permeability rock, (2) sufficient volume of host rock, and (3) no conflicts with natural resources (HSK 1999).

In 1978, motivated by the Swedish program, Nagra launched Project Gewähr (loosely translated as "guarantee") to investigate the possibility of developing a deep-mined, geologic repository for HLW and SNF (as well as long-lived, intermediate-level waste) in crystalline rock. The following year, it applied to construct a URL in the Grimsel region outside of Bern.

Three technical criteria guided the search for potential sites: tectonic stability, low faulting, and ease of construction. Crystalline rock formations satisfying these criteria can be found only in northern Switzerland in a relatively small area covering the cantons of Solothurn, Aarau, Zurich, and Schaffhausen. Between October 1982 and February 1985, six boreholes were drilled. These surface-based investigations produced one especially surprising result. The crystalline basement rock was intersected by a large sedimentary trough, the so-called Permo-Carboniferous Trough. Although this discovery strongly called into question the claim that there was a large body of non-fractured crystalline rock in northern Switzerland, Nagra continued to promote the development of a repository in granitic host rock for another ten years (Nagra 1994).

In 2004, the Swiss regulator, HSK (now ENSI), concluded that the granite concept might be safely implemented for HLW but that the likelihood of finding a suitable site had not increased over the previous decade and a half.

Box 4. Searching for a granite site in Switzerland

- Host-rock stability
- Favorable host-rock geologic properties
- Avoidance of detrimental phenomena
- Insensitivity to detrimental phenomena
- Explorability
- Predictability

Studies carried out in the Opalinus clay formation and the Lower Freshwater Molasse led the latter to be classified as a "reserve option" primarily because of its greater heterogeneity, higher permeability, and substantial obstacles to characterization (SFOE 2008:18). (See Figure 11.)

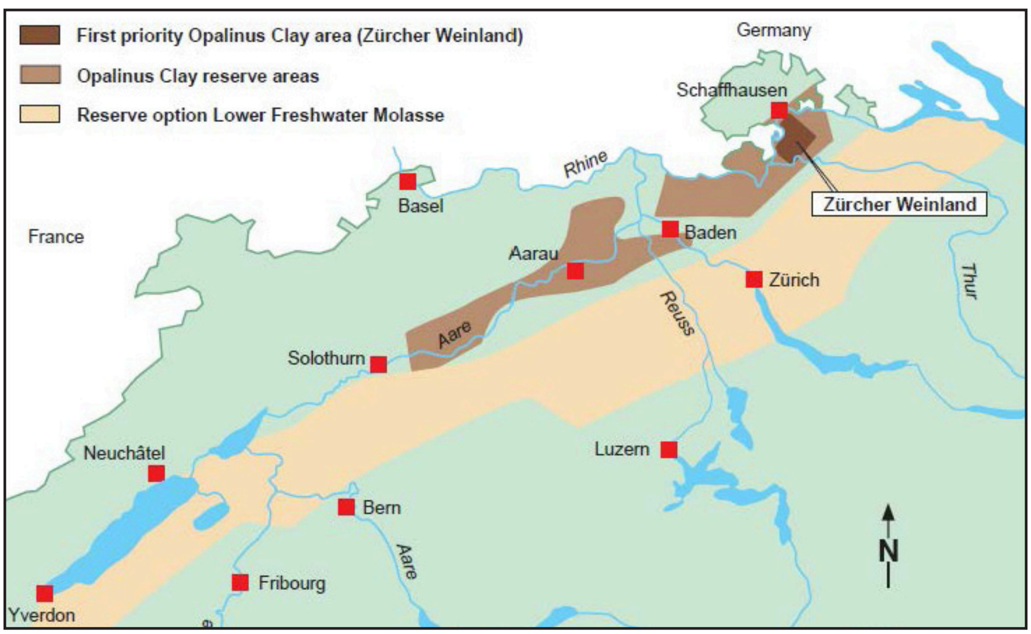

Figure 11. Prospective settings in Switzerland (Source: Nagra 2002b)

Opalinus clay emerged as the preferred host rock because (Nagra 2002a:63-64):

- The geological environment is simple, with predictable structural, hydrogeological, and geochemical properties over a scale of several kilometers.
- The formation is tectonically stable on a timescale of the next few million years.
- The mechanical properties of the clay ensure that repository-induced or natural discontinuities are self-sealed.
- The formation has very low hydraulic conductivity.
- The overburden does not contain significant natural resources.
- The geochemical environment has been stable for millions of years, is reducing, and has strong sorptive capacity.
- The formation has good engineering properties, facilitating repository construction.

Based on three-dimensional seismic soundings and an exploratory borehole near Benken in the Zürcher Weinland, Nagra proposed that a site in that area be selected.

The Federal Council concluded that, along with safety and engineering feasibility, siting feasibility had now been demonstrated. But recognizing that a choice of one is no choice, it asked the Federal Office of Energy to develop a more comprehensive, transparent, and participatory process to find sites for two deep-mined, geologic repositories: one for HLW and SNF, and the other for long-lived low- and intermediate-level radioactive waste.

The resulting Sectoral Plan established a three-stage process (SFOE 2008). Stage 1 concluded at the end of 2011 when the Federal Council accepted Nagra's recommendations of five regions in the Opalinus clay. Shortly thereafter, the implementer proposed as many as 33 possible sites where the surface facilities for the repositories might be located (Nagra 2012). As Stage 2 progressed, those 33 sites were reduced to seven. Figure 12 below shows the regions and the remaining surface-facility sites.

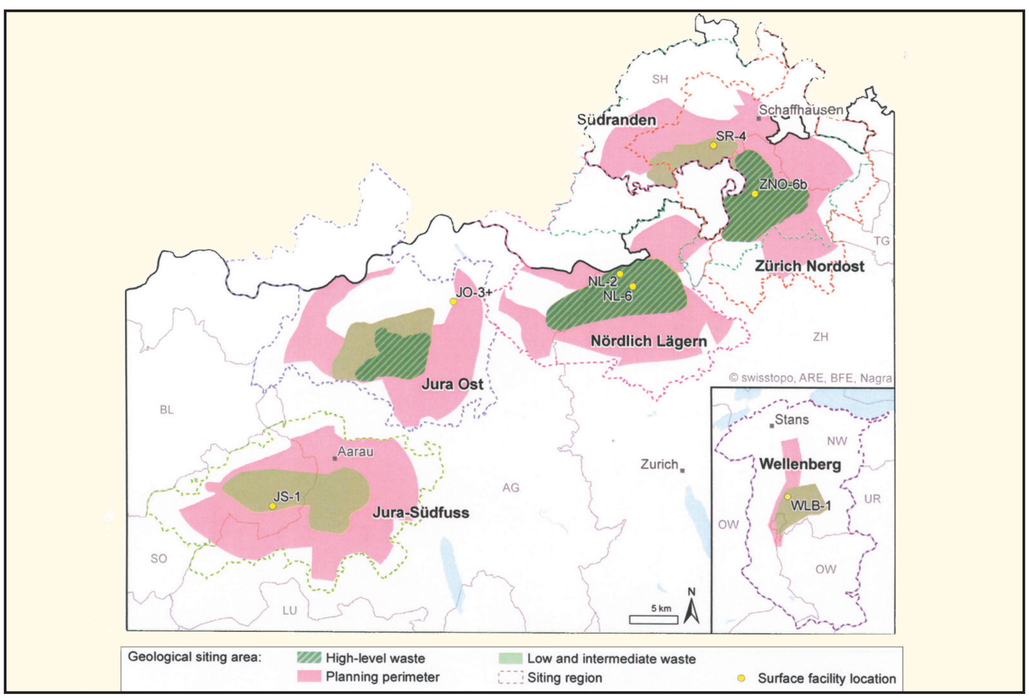

Figure 12. Selected regions and proposed sites for a repository's surface facilities in Switzerland (Source: SFOE 2014b)

Belgium

Policymakers in Belgium have not officially determined whether a deep-mined, geologic repository will be the centerpiece of the country's strategy for the long-term management of HLW and SNF. Nonetheless, the country's public sector implementer, the National Agency for Radioactive Waste and Enriched Fissile Material (ONDRAF/NIRAS), has been concentrating since 1974 on two poorly indurated clay formations: Boom and Ypresian.[43] This interest was stimulated both by a study undertaken by the Commission of European Communities (CEC 1980) and by the practical constraint that suitable salt or granite formations are difficult, if not impossible, to find within the country.[44]

ONDRAF/NIRAS will prepare safety cases for facilities in Boom and Ypresian clay. In doing so, it will use site-specific data from Mol-Dessel and Doel, respectively. The implementer, however, will also evaluate the advantages and disadvantages of extending the prospective settings to a larger zone. Recently, ONDRAF/NIRAS received some draft site-suitability criteria from its regulator, the Federal Agency for Nuclear Control. Belgium's upcoming response to a 2011 European Union directive may become the vehicle for pursuing a geologic repository.

Generic Criteria (Multiple Disposal Concepts)

Using Host-Rock-Specific Criteria to screen for prospective settings and potential sites is a strategy best fitted for countries where, for a variety of reasons, only one disposal concept can practicably be deployed. In other nations, where multiple concepts might be successfully adopted, a *fundamentally different approach is needed*. How such site-suitability criteria came to be fashioned and implemented is described in this subdivision of this report.

Throughout the 1960s and early 1970s, discussions about siting deep-mined, geologic repositories for HLW and SNF were singularly focused on the host rock as opposed to the wider hydrogeologic environment and the engineered barrier system. Perhaps the most striking illustration of this was the four-volume "Technical Alternatives" study prepared for the U.S. Energy Research and Development Administration (ERDA).[45] Only one thin chapter in that massive report was devoted to "non-salt" alternatives (ERDA 1976). Within two years, however, that perspective would undergo a fundamental shift both in the United States and internationally: the singular focus on the salt-centric disposal concept gradually broadened as other possibilities emerged.

One sign of the shift was that several international organizations initiated exploratory assessments to identify Generic Criteria that suggested site suitability. The IAEA, for instance, engaged a German and an American scientist to develop criteria for evaluating sites. The specialists concluded, however, that "because of the complexity of the overall concept and variations in the properties of the radioactive waste and of the geological formations, it was not feasible to develop specific criteria" (IAEA 1977:1). Instead, they pro-

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[43] These formations are quite different from Opalinus clay in Switzerland and the Callovo-Oxfordian argillite in France, especially when it comes to their geomechanical properties.

[44] The shale in southern Belgium is much more complex than Opalinus clay or Callovo-Oxfordian argillite, has rather limited continuity, and is difficult to characterize from the surface. Thus this host rock is being held in reserve as a fallback position. Having to utilize the shale concept would impose significant costs to develop new knowledge to support a novel disposal concept and would lead to programmatic delays.

[45] In 1984, Congress abolished the AEC and transferred its energy-development responsibilities, including radioactive waste management, and its nuclear weapons production responsibilities to ERDA. In 1987, Congress abolished ERDA and transferred its responsibilities to the new Cabinet-level DOE.

posed the listing that is provided in Box 5 below. Although it had little immediate impact, the listing framed discussions that would take place over the next five years.[46]

1. Spatial distribution of the rock—characteristics of the containing rocks
   a. Homogeneity of the rock mass
   b. Three-dimensional geometry
   c. Geological structure including faulting

2. Fluid-flow factors—possible mechanisms for transport of radionuclides away from a repository
   a. Rock parameters, including permeability,* porosity,* and dispersiveness*
   b. Regional hydrological and hydrogeological conditions

3. Long-term stability of the rocks—integrity of the repository and containment of the wastes
   a. Solubility
   b. Plasticity
   c. Mechanical integrity
   d. Thermal integrity
   e. Radiation integrity
   f. Diapirism
   g. Geodynamic conditioning
   h. Seismicity
   i. Volcanism
   j. Operational safety and stability

4. Geochemical parameters—influenced by the operation of the repository and influencing the effectiveness of the containment
   a. Sorption properties (adsorption and absorption)
   b. Thermal effects
   c. Gas and liquid inclusions
   d. Mineral constituents of water

5. Future geological events—external to the repository site
   a. Erosion
   b. Glaciation
   c. Flooding

6. Resource potential—possibility of human intrusion

* Subject to modification by secondary thermal and mechanical effects.

Box 5. Generic Criteria that can affect repository performance (Source: IAEA 1977)

United States

In the United States, even as scientists at the Pacific Northwest Laboratory were working on the "Technical Alternatives" document, a compounding sequence of events led first the AEC and then ERDA gradually to embrace the shift away from site-suitability criteria based on Host-Rock-Specific Criteria to those relying on Generic Criteria.[47] That shift is described below.

The AEC's attempt to develop a "demonstration repository" in Lyons, Kansas, was terminated in 1972 because technical miscalculations and blunders reverberated in the political sphere. (These will be discussed in greater detail later in this report.) The agency's

[46] Although some discussion of directly disposing of SNF had taken place by this time, the prevailing presumption was that the solidified HLW would be the waste form that would be emplaced in a repository. It was only after 1980 that the possibility of direct disposal of SNF became an important policy option.

[47] For a fuller discussion of the events leading to that shift, see OTA 1985:209-212.

first reaction was to propose the creation of a Retrievable Surface Storage Facility (RSSF), essentially a concrete pad where canisters holding HLW and SNF accepted from commercial reprocessing plants and reactors could be held in dry storage casks until they could be disposed of in a deep-mined, geologic repository.[48] The agency issued a draft Environmental Impact Statement (EIS) in support of this initiative (AEC 1974). But the RSSF never enjoyed much political support, and strong criticism from the Environmental Protection Agency (EPA) served up the *coup de grace* for the proposal.

> A major concern in employing the RSSF concept is the possibility that economic factors could later dictate utilization of the facility as a permanent repository, contrary to the stated intent to make the RSSF interim in nature. … [I]t is important that [environmental factors] never be allowed to become secondary to economic factors in the decision-making process. Vigorous and timely pursuit of ultimate disposal techniques would assist in negating such a possibility.[49]

Prudently, at the same time it was advocating the construction of the RSSF, the AEC launched its Geologic Storage Alternative Program. A major component of that project was exploration of the bedded-salt Salado Formation in the Los Medaños area, some 30 miles southeast of Carlsbad, New Mexico. More detailed geologic, petrologic, stratigraphic, structure/tectonic, and hydrologic studies were conducted. With the encouragement of the town's leaders, although with some resistance from state officials, this area was ultimately chosen as the site for a deep-mined, geologic repository to dispose of transuranic waste from the nuclear defense complex.[50] Box 6 provides a brief description of how that siting choice was made.

The AEC's expanded program also supported investigations in areas previously discounted prior to the setback in Lyons, Kansas. Disposal in salt still remained the dominant focus. But serious attention was paid for the first time to the salt formations outside of the Permian Basin. The AEC sought to explore prospective settings in Michigan, Pennsylvania, Ohio, New York, Utah, and along the Gulf Coastal Plain. (See Figure 6 on page 33.) It sponsored studies by the U.S. Geologic Survey (USGS) in the Pierre Shale in the Upper Midwest. It also began to investigate possible basalt sites on the Hanford Reservation in eastern Washington and the volcanic tuff formation at Yucca Mountain on the Nevada Test Site.[51]

EPA's letter criticizing the RSSF arrived at AEC headquarters a mere 59 days before the agency would be disbanded in January 1975. With an important element of the nation's waste-management policy no longer viable, the newly established ERDA decided to reinvigorate and significantly expand the repository-siting projects that it had inherited from

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[48] "If the problems of gaining public acceptance of the concepts of storage [sic] in geological formations cannot be overcome in the near future, an available option is retrievable storage in carefully engineered man-made structures." AEC, "High-Level Waste Management," SECY-2271, January 25, 1972, 3.

[49] Letter from Sheldon Meyers, Director, Office of Federal Activities, EPA, to James Liverman, Assistant General Manager for Biomedical and Environment Research and Safety Programs, AEC, November 21, 1974, Enclosure at 2.

[50] The resistance from state officials will be discussed in greater detail when the WIPP siting effort is considered in the section of this report dealing with the Social Acceptability Filter.

[51] The land at both locations was owned by the federal government, and each site had played important roles in the U.S. nuclear weapons program.

The technical and political controversy surrounding the Lyons site caught the attention of Carlsbad, New Mexico's State Senator Joe Gant, who recognized a promising opportunity. Mobilizing community and state officials, he launched a sophisticated lobbying effort over the next 18 months to site a repository in the Delaware Basin. (See Figure 6 on page 33.) That effort meshed well with the AEC's redirected waste-management program to develop a facility, called the Bedded Salt Pilot Plant, to demonstrate the safety of deep-mined, geologic repositories.

In August 1972, the AEC announced that it would investigate sites in southeast New Mexico, and six months later Oak Ridge National Laboratory concluded that the geology in that area "appears to be most promising." The laboratory, however, cautioned about the potential for future petroleum exploration but observed that its adverse impact could be mitigated by careful site selection. Within a year, a location approximately 30 miles east of Carlsbad, ERDA-6, was chosen for exploratory work and field evaluations. The strong support of the Carlsbad community encouraged two successive New Mexico governors to maintain a neutral position toward the decision to site WIPP.

In June 1975, a borehole drilled at ERDA-6 encountered pressurized brine and revealed that the bed dipped steeply up to angles of 75°. Almost immediately, that site was abandoned. A new area seven miles to the southwest, ERDA-9, was selected, but only after the guideline on how close the site could be to existing oil and gas boreholes was reduced from two miles to one mile.

In 1976, ERDA requested that the Bureau of Land Management withdraw from public use a 17,200 acre land tract around the site to prevent the drilling of new oil and gas exploratory boreholes. That request was swiftly approved and renewed two years later.

Technical challenges to the suitability of the site were advanced, including one by Roger Anderson, a professor of geology at the University of New Mexico. The critics maintained that evidence had been found of flowing water dissolving the salt and creating "collapse features" below the site. A review committee empaneled by the NAS, however, disagreed with this interpretation and recommended that site investigations continue.

In April 1979, ERDA issued a draft EIS to support the construction of a deep-mined, geologic repository for the disposal of both commercial HLW and SNF and defense-origin transuranic waste. Congressional opposition to the former activity forced WIPP's mandate to be limited to the latter.

The IRG recommended that WIPP not be developed simply to dispose of defense-origin transuranic waste. President Carter accepted this recommendation. But his decision to terminate the project was rebuffed by Congress, which authorized the construction of WIPP in the 1979 DOE National Security and Military Applications of Nuclear Energy Authorization Act. In 1992, Congress passed the WIPP Land Withdrawal Act, clearing the way for the site's selection. Six years later, EPA certified that the planned repository met the regulator's requirements.

Box 6. Siting the Waste Isolation Pilot Plant (WIPP)

the AEC. About a year later, the National Terminal Waste Storage program, managed by the Office of Waste Isolation located at ORNL, began its work.[52]

ERDA's new program was to have surveyed prospective settings in different host rocks found in 36 states and, through a four-step winnowing process, was to have constructed six regional repositories by 2000.[53] However, from the start, the agency encountered local

[52] The Office of Waste Isolation oversaw all of ERDA's siting work except for the pilot repository at Carlsbad, which reported to the Albuquerque Operations Office.

[53] A detailed description of ERDA's hoped-for program is found in Lomenick 1996:31-34 and Lomenick 1996:Appendices C and D.

opposition, some of which was based on the claim that the Federal Government lacked the legal authority to evaluate potential sites without permission from the affected state (Carter 1987; EPRI 2010a).[54]

That opposition forced a pause in activity, which allowed a strong technical basis for the fresh perspective on siting to be established and to be consolidated through an unprecedented political process led by the White House. (Carter 1987:135-139 summarizes these events.)

A study group convened by the American Physical Society and a critical essay authored by scientists from the USGS laid the first technical foundations for the new paradigm (Hebel et al. 1978; Bredehoeft et al. 1978).[55] Those studies argued that, while the ability of the host rock to isolate and contain radionuclides was invaluable, other geologic factors could play a critical role. This perspective supplied the rationale for considering host rock other than salt.

It was the IRG, however, that most authoritatively pointed out the limitations of a site-selection process that focused solely on a repository's host rock.

> The fate of radionuclides over thousands of years in a repository will be determined by the cumulative effect of the hydrogeologic, geochemical, and tectonic characteristics of the environment and by future human activities as well as by the physical and chemical properties of the host rock chosen for waste emplacement, the waste form, and other engineered aspects of the repository. *No single property, characteristic, or human action alone will determine the fate of the radionuclides. Therefore, the waste form, the repository, and the environment of the repository are best viewed and analyzed as a system* [emphasis added] (IRG 1978:Aiii).

After more than three years of debate, Congress adopted this "systems perspective" when it passed the NWPA in December 1982. Once the properties of the host rock receded in importance for site selection, however, creativity would be needed to find an alternative framework.

The NWPA did establish a firmer legal basis for any future repository site-selection process. Not fully appreciated at the time, however, the law also contained within it the seeds of its own collapse: it sought to establish a technically driven, objective strategy for identifying potential sites and for choosing among them, but enacted unrealistic schedules for doing so. As one observer noted:

> While potential host states were given the assurance of a rational, participatory siting process, this assurance was effectively denied, at least in the case of the potential hosts for the first repository. … Congress had in a sense grandfathered the sites in the Department's existing inventory—sites which the host states had no voice in selecting (Carter 1987:229).[56]

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[54] Between 1977 and 1983, few on-site investigations were conducted. During that time, ERDA-directed activities revolved around reorganizing the National Waste Terminal Storage program as management contractors came and went, shuffling responsibility for studying different host rocks among various operations offices and preparing a Generic Environmental Impact Statement (DOE 1980a) ratifying the choice of a deep-mined, geologic repository as the preferred method for the long-term management of HLW and SNF. The reasons for the inactivity are considered in this report's section on the Social Acceptability Filter.

[55] This "new" paradigm was clearly foreshadowed when the AEC expanded its siting efforts beyond bedded salt in 1972 and by the KBS-3 method, which was just gaining international prominence.

[56] The conflict that Carter refers to is between Section 112(a) and Section 116(a) of the NWPA.

This report details in the section on the Social Acceptability Filter how the contradiction permeated efforts to site a repository for a quarter of a century.

The newly created DOE Office of Civilian Radioactive Waste Management (OCRWM) had two urgent matters to address when it opened for business in January 1983. Within 90 days of the passage of the NWPA, it had to recommend “potentially acceptable sites.”[57] Within 180 days of the passage of the Act, it had to “issue guidelines for the recommendation of sites for repositories.” How did OCRWM juggle these two pressing tasks?

Beating the enacted schedule, DOE designated nine sites as potentially acceptable in February 1983. The NWPA required only that the sites had to be chosen “after geologic studies and field mapping but before detailed geologic data gathering.”[58] This condition could easily be met because, as this report notes above, previous work by DOE and its predecessor agencies had, in fact, created a portfolio of prospective settings.[59]

Most of the settings were in either bedded or domed salt. Along the Gulf Coastal Plain, 125 salt domes were studied. Based on the depth of the salt, the lateral extent cross-sectional area at repository depth, and existing competing uses, seven locations were considered as potentially acceptable. Three of these were dropped from further consideration because of their small size and a fourth was eliminated because of conflicts with known petroleum reserves. What remained were the formations at Cypress Creek and Richton in Mississippi and Vacherie Dome in Louisiana.

In the Paradox Basin, four areas were considered. Two were deferred because the salt formations were too close to zones of mapped surface faults. In a comparison of the Gibson Dome and the Elk Ridge salt beds in Utah, the former seemed more suitable because of its thickness and distance from salt dissolution features. Three specific sites within Gibson Dome were then evaluated, and Davis Canyon and Lavender Canyon survived the winnowing exercise.

Finally, in the Permian Basin, three sub-basins were screened. One was eliminated because of extensive oil and gas drilling.[60] Six locations in two sub-basins were studied in greater detail. Based on the geomorphology, absence of natural resources, limited numbers of existing boreholes, low population density, and land-use conflicts, two potentially acceptable sites, in Deaf Smith and Swisher Counties, Texas, were chosen.

The AEC and ERDA’s timely decision to expand their search for prospective settings also led them to initiate studies at the federally owned land tracts at the Nevada Test Site and at the Hanford Reservation in eastern Washington. Based on evaluations of geologic and hydrologic suitability and environmental factors, five sites in the former location and nine

[57] “Potentially acceptable sites” are synonymous with potential sites as used in this report. When discussing the siting history in the United States, the former construction, which is legally defined, will be used.

[58] NWPA Section 116(a).

[59] What follows draws on Lomenick 1996:115-116. As this report describes in greater detail in the section on the Social Acceptability Filter, opposition from state officials typically prevented fieldwork at the prospective settings in salt. Even after the passage of the NWPA, study of the Salina Basin in Michigan, northern Ohio, and western Pennsylvania and New York was deferred “due to state/federal politics” (Lomenick 1996:113).

[60] The Delaware Basin was dropped from consideration because it had already been selected as the site where transuranic-contaminated waste from the defense program would be disposed of at WIPP.

in the latter were considered.[61] Formal decision analyses were carried out, resulting in the choice of Yucca Mountain (either in the saturated or unsaturated zone) and the "Reference Repository Location" at Hanford (Lomenick 1996:115-117). Those studies enabled DOE to satisfy the IRG recommendation that multiple host rocks be considered, and, more important, the NWPA provision requiring DOE "to consider the various geologic media in which sites for repositories may be located and, to the extent practicable, to recommend sites in different geologic media."[62]

Figure 13 shows the location of the nine potentially acceptable sites that DOE selected.

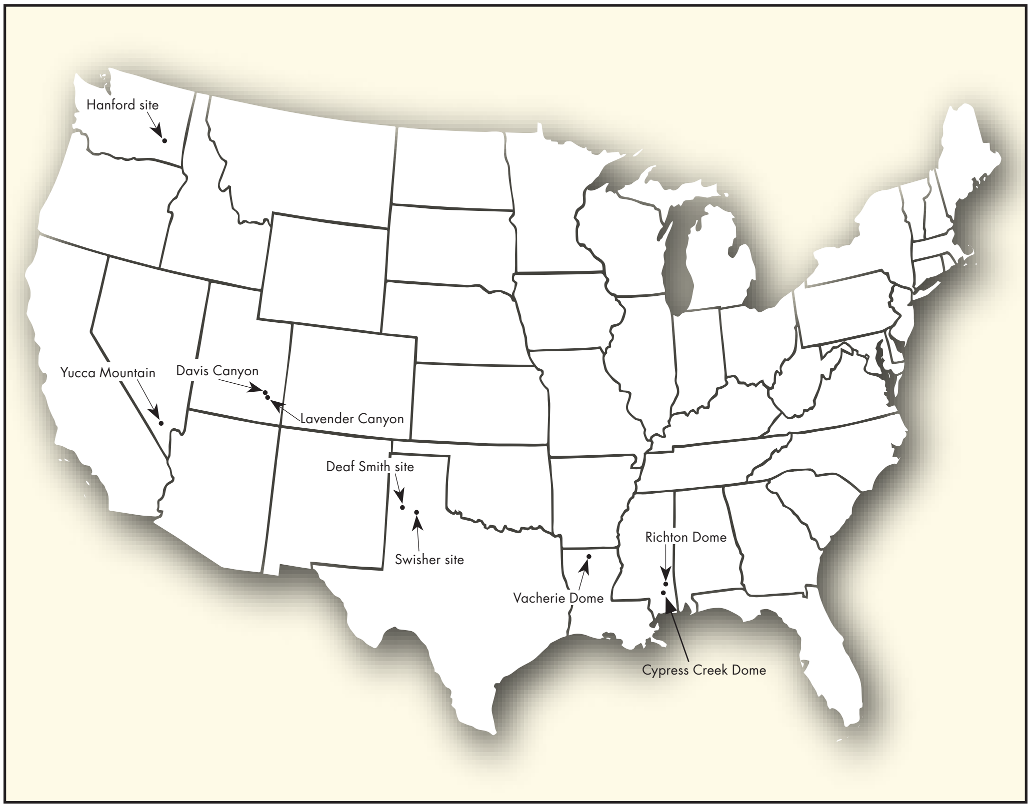

Figure 13. Potentially acceptable sites for the first repository in the United States (Based on Lomenick 1996)

Even as OCRWM was working to recommend potentially acceptable sites, it was organizing a task force to comply with the second early NWPA milestone to develop guidelines for recommending potential sites for repositories. Among other things, the guidelines had to:

> … specify *detailed geologic considerations that shall be the primary criteria* for the selection of sites in various geologic media. Such guidelines shall specify factors that qualify or disqualify any site from development as a repository, including factors pertaining to the location of valuable natural resources, hydrology, geophysics, [and] seismic activity … [emphasis added] (NWPA Section 112[a]).[63]

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[61] These criteria are provided in Appendix 4.

[62] NWPA Section 112(a).

[63] The complete list of criteria is provided in Appendix 5.

In February 1983, DOE published draft *Siting Guidelines* that codified the qualifying, favorable, potentially adverse, and disqualifying conditions for determining whether a particular site was suitable for development as a deep-mined, geologic repository (DOE 1983a).[64] When ultimately finalized (more than 18 months late) in December 1984, the *Siting Guidelines* rested on a three-element foundation (DOE 1984c):

- Implementation guidelines establish general rules to be followed in the process of selecting a site for repository development.
- Technical criteria
  - Postclosure guidelines govern the siting considerations that deal with the long-term behavior of a repository.
  - Preclosure guidelines delineate the siting considerations that affect the construction and operation of a repository.[65]

The implementation guidelines specify a three-step process beginning with identification of a suite of potentially acceptable sites, nomination of at least five sites that are suitable for characterization, and finally a recommendation to the President of three sites where detailed investigations, including underground exploration, would be conducted.

The postclosure criteria include one system guideline, which mandates that the repository system comply with the environmental standard established by EPA, and ten technical guidelines.

Some of the technical guidelines detail geological characteristics affecting expected repository performance (i.e., geohydrology and rock characteristics), while others seek to minimize the likelihood of disruptive processes and events (i.e., tectonics and human intrusion). For instance, a site located in the saturated zone would be expected to exhibit a "low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units" [DOE 1984c:960.4-2-1(b)(4)(ii)]. Conversely, in regard to the geochemical properties of a site, locations were to be avoided where "processes or conditions … could reduce the sorption of radionuclides or degrade the rock strength" [DOE 1984c:960.4-2-2(b)(2)]. A favorable condition for a site would be that "no known natural resources have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource" [DOE 1984c:960.4-2-8-1(b)].

Importantly, the *Siting Guidelines* spelled out postclosure Exclusion Criteria that would eliminate a potential site outright.

- Pre-waste emplacement groundwater travel time from the disturbed zone to the accessible environment is less than 1,000 years along any pathway of likely and significant radionuclide travel.
- Site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.
- During the first 10,000 years after closure, subsurface active rock dissolution resulting in loss of waste isolation is likely, as predicted on the basis of the geologic record.

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[64] For an excellent discussion of DOE's *Siting Guidelines*, see EPRI 2010a:3-3 – 3-12. DOE's Generic Criteria are remarkably similar to those laid out in NAS 1978.

[65] Because DOE maintained that its evaluation of sites would, in the final analysis, "place primary significance on the postclosure guidelines and secondary significance on the preclosure guidelines" (DOE 1984c:960.3-1-4-3), the preclosure guidelines will be discussed only in passing in the rest of this report.

- Based on the geologic record during the Quaternary Period, the nature and rates of fault movement and other ground motion are expected to be such that a loss of waste isolation is likely to occur.
- Previous exploration, mining, or extraction activities for resources have created significant pathways between the repository and the accessible environment, or ongoing efforts to recover resources would be expected to lead to an inadvertent loss of waste isolation.

Among other things, the following two subdivisions of this report describe, respectively, how the *Siting Guidelines* was finalized and how it was applied to narrow the nine potentially acceptable sites for the *first* repository down to three that would be recommended for characterization. For the moment, however, the focus is on how the *Siting Guidelines'* technical requirements were applied to screen prospective settings and potentially acceptable sites for the *second* repository.

The NWPA anticipated that a second facility would be constructed in a different part of the country to supplement the one developed at a site already identified in DOE's inventory. Relying on the draft *Siting Guidelines* for its technical rationale, in April 1983 DOE published a national survey that recommended further study of crystalline rock formations in 17 states concentrated in three regions, all east of the Mississippi River (DOE 1983b:81-82).[66] DOE explicitly rejected possible sites in crystalline rock in seven western states because the NWPA requires that consideration be given to the need for geographic equity when planning for the second and subsequent repositories. [67]

Although criticized heavily by scientists from the affected states (Halstead et al. 1988), the national survey tightly framed all subsequent discussions of the so-called Second Round. A month after the review's publication, DOE issued draft environmental and characterization reports for each region.[68] The objective of those reports was to support narrowing the real estate from regions to areas. Altogether 235 prospective settings, called "rock bodies" in the reports, were identified.

Because of the political controversy evoked with the reports' releases, DOE decided to develop a methodology for applying the site-suitability criteria contained in the then-draft *Siting Guidelines*. The methodology would evaluate the Exclusion Criteria and 20 additional geologic and environmental variables to assess the suitability of each of the 235 prospective settings (DOE 1985a). DOE invited state officials to three workshops to provide preliminary input to a draft methodology report, which was released in September 1984. Twenty-seven comments were received from state governments. Among the most significant concerns raised were whether weighted or unweighted variables should be used and how DOE would handle differences in the quality and comprehensiveness of available data (DOE 1985a: Appendix A).

In April 1985, DOE circulated the final methodology (DOE 1985a). As one participant recalled, "DOE adopted a number of state recommendations, but rejected many others, and the final screening methodology was very controversial" (Halstead et al. 1988:902).

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[66] North Central Region (Michigan, Minnesota, and Wisconsin); Northeastern Region (Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont); Southeastern Region (Georgia, Maryland, North Carolina, South Carolina, and Virginia)

[67] Arizona, Idaho, Montana, Oklahoma, South Dakota, Texas, and Wyoming.

[68] Because of strong state criticism, the draft characterization reports were reissued in December 1984.

Part of the controversy undoubtedly arose because of the complexity of the final methodology. At the core of the approach was a geographic information system that mapped the 235 prospective locations onto a system of a 500,000 one-mile-square grid cells. Each cell was evaluated by assigning a score (one to five) to each of the five elements of the Exclusion Criteria and the 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 aggregate suitability scores for each prospective setting. In January 1986, a draft *Area Recommendation Report* was published (DOE 1986a). Using this methodology, 12 potentially acceptable and eight candidate (back-up) rock bodies in seven states were selected.[69] These are listed in Table 4.

Region	State	Rock Body	Areal Extent (miles²)
Proposed Potentially Acceptable Sites			
North Central	Wisconsin	Wolf River Batholith	1,094
	Minnesota	Undifferentiated Granites	300
	Minnesota	Undifferentiated Granites	113
	Minnesota	Archean Gneisses/Central Minnesota Granites	397
Northeastern	Maine	Bottle Lake Complex	92
	New Hampshire	Sebago Lake Batholith	385
	New Hampshire	Cardigan Pluton	78
Southeastern	Virginia	Lovingston Massif	209
	Virginia	Virgilina Gneiss	307
	North Carolina	Rolesville Pluton	142
	North Carolina	Elk River Complex	105
	Georgia	Woodland Gneiss Complex	214
Proposed Candidate Areas			
North Central	Wisconsin	Puritan Batholith	171
	Minnesota	Undifferentiated Granites	249
	Minnesota	Archean Gneisses	171
	Minnesota	Archean Gneisses	60
	Minnesota	Archean Gneisses	287
	Minnesota	Undifferentiated Granites	70
Southeastern	Virginia	Fredericksburg Complex	64
	Georgia	Lithonia Gneiss	67

Table 4. Area designations for the second repository in the United States (Source: DOE 1986a)

[69] Nine of the 12 potentially acceptable sites were among the most favorable on all nine sets of variable weights.

France

The paradigm shift away from Host-Rock-Specific Criteria to Generic Criteria applicable to multiple concepts independently took root in Europe as well. In France, the government-established Castaing Commission provided a broad overview of site-selection criteria, dose limits, and strategies for identifying potential sites (Castaing 1984). Three years later, another group, led by the distinguished French geologist Jean Goguel, advanced a set of Generic Criteria that could be used to site a repository (Goguel 1987).[70]

Like DOE's *Siting Guidelines*, Goguel's group proposed a hierarchical set of requirements. Only two *essential criteria* were suggested: the hydrogeological properties of the site (permeability of the host-rock formation and hydraulic gradient) and its geologic stability (degree of seismicity, faulting, and erosion). *Important criteria* included mechanical, geochemical, thermal, and groundwater properties as well as minimal depth requirements. Finally, *favorable factors*, including dilution of the discharge and distance to the discharge outlet, were suggested.

Based on recommendations from the French Bureau of Geological and Mining Research, the then-implementer, the French Atomic Energy Commission (CEA), selected four sites for investigation. (See Table 5.) The communities involved were not notified about their selection until CEA researchers arrived (Mays 2004). The decisions were, as one analyst put it, "public but not published."[71]

Site	*Département*	Host Rock
Neuvy-Bovin	Deux-Sèvres	Granite
Sègre	Maine-et-Loire	Schist
Champagne Septentrionale	Aisne	Clay
Sel Bresse Merdionale	Ain	Salt

Table 5. Proposed site investigations in France during 1987-1990 (Source: Kemp 1992)

Plans for preliminary investigations included deep drilling (up to 1,000 meters) and airborne and surface geophysical surveys: for example, 1,500 kilometers of airborne radiometric surveys at Deux-Sèvres; 15 kilometers of helicopter-borne geophysical profiles plus 13 kilometers of ground measurements at Maine-et-Loire; 150 kilometers of seismic lines from the area around Aisne; and 30 kilometers of gravity surveys near Ain (SKN 1992:43).

Demonstrations against the investigations followed. In their wake, the Prime Minister, Michel Rocard, declared a moratorium and set in motion a parliamentary process to revise France's siting strategy. A new law governing the long-term management of HLW and SNF passed in 1991. The next subdivision of this report describes how that law's site-selection process was implemented.

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[70] The group noted in the conclusion of its report that its "approach was to define, to the extent possible, the criteria or recommendations common to all geological environments considered generically" (Goguel 1987:57). The group did, however, suggest that some additional Host-Rock-Specific Criteria might have to be considered as well. A complete listing of the criteria suggested by Goguel's group is found in Appendix 6.

[71] The choice of the schist and salt sites was dictated by the fact that very few places met the minimal site-suitability requirements. The granite site was picked because it was large and had few fractures, and the clay site was chosen because it was relatively close to Paris, where the unit within the CEA responsible for repository siting has its headquarters.

In 1999, the Federal Government sponsored an initiative that proposed stepping away from a siting strategy focusing only on salt as a host rock and moving to a more generic one (Appel 2006). Even today, however, it is unclear where that road might ultimately lead.

Confronted with more than two decades of technical and political controversy over designation of potential sites in the Lower Saxony salt domes, and, in particular, the presumptive choice of Gorleben, the Federal Minister of the Environment in 1999 created a Committee on a Selection Procedure for Repository Sites, colloquially called AkEnd, (AkEnd 2002). As one study put it, the committee was established to propose a "siting process designed to identify *the best-possible* repository site in Germany without any spatial pre-selection and predetermination of the host rock" (COWAM 2006:46). In effect, from a "white map" of Germany, candidate sites would be pinpointed.

Starting with ten requirements, such as "no or slow radionuclide transport" and "good temperature compatibility," AkEnd developed Generic Criteria that included, among others, the following requirements:[72]

- The rock types and their characteristics should spatially be as evenly distributed as possible within the isolating rock zone.
- The specific hydraulic gradient in the isolating rock zone should be low (less than 10^{-2}).
- The sorption capacity (K_d) of the rocks should be as high as possible. The K_d value for the majority of the long-term-relevant radionuclides should be greater than or equal to 0.001 m^3/kg.

Five Exclusion Criteria would remove a site from any further consideration (AkEnd 2002:21).

- The repository area must not show large-area uplifts of more than one millimeter per year on average during the predictable period.
- There must not be any active fault zones in the repository area.
- In the repository area, the expected seismic activity must not be higher than in Earthquake Zone 1.
- In the repository area, there must be neither Quaternary nor any expected future volcanism.
- In the isolating rock zone, there must not be any young groundwater. The groundwater must therefore not contain tritium or carbon-14, isotopes possessing short half-lives.

AkEnd deliberated for three years. Ultimately, even its sponsor concluded that the political landscape was too inhospitable to move forward with the group's proposals (Hocke and Renn 2009).

By July 2013, however, the environment had apparently changed; the German Parliament approved by wide multi-partisan majorities the Repository Site Selection Act. A cornerstone of that law is the creation of a Commission for the Storage of High-Level Waste, which has been directed to develop the basic principles and scientific criteria for a site-selection procedure by the end of 2016. The 32-person commission, made up in equal parts of Federal legislators, representatives of the *Länder*, members of civil society, and experts, got off to a slow start, holding its first meeting in May 2014. In early 2015, the group recommended that the organizations of both waste-management implementer and regulator be restructured. On

[72] For a complete listing, see Appendix 7.

the surface, the multi-partisan consensus appears to be holding two years after the law's passage. But the ultimate fate of this initiative still hangs in the balance.

China

China has a long-standing program to site a deep-mined, geologic repository for vitrified HLW. Initially, focus was placed exclusively on prospective sites in granitic host rock.[73] A stepwise process was initiated. The Host-Rock-Specific Criteria used to guide site selection include the geology of the granite formation, hydrogeology, geochemistry, and the future evolution of the facility (Rui 2014). Up until now, the site-suitability criteria have not included single features that would automatically eliminate a site from further consideration.

The organization that first led the siting effort was the Beijing Research Institute for Uranium Geology (BRIUG), a subsidiary of the state-owned China National Nuclear Corporation. BRIUG investigated six regions scattered throughout the country, including in Xinjiang and Gansu Provinces in the northwest, Inner Mongolia, and central, eastern, and southern China. The Beishan area in Gansu Province emerged as the leading region. The next step in the process would have been to narrow seven potential sites at Beishan down to one.

Recently, the repository siting process has changed. The new process calls for the identification of 12 potential sites for a repository, which, through some yet-to-be-defined methodology, would be narrowed to three candidate sites. BRIUG continues to evaluate prospective settings in granite in Gansu Province to determine their suitability both for a URL and for a deep-mined, geologic repository.[74] The East China Institute of Technology is just starting to evaluate prospective settings in clay host rock in Inner Mongolia, Quinghai, and along the Gansu-Shaanxi border.[75] It is unclear at this time whether clay will emerge as a viable contender to granite.[76] Figure 14 shows the location of the Beishan site in relation to some of China's major population centers.

Exclusion Criteria (Single and Multiple Disposal Concepts)

The discussion above on how Technical Suitability Filters were used to identify prospective settings and potential sites also illustrated how the implementer employed Exclusion Criteria. However, by the turn of the 21st century, it had become increasingly clear that siting processes driven solely by the judgments of the implementer were encountering significant political obstacles. Volunteerism, in various forms, emerged as an essential component of national waste-management programs that were either initiating a new siting effort or trying to reinvigorate an old one. Of course, not all volunteers control suitable real estate, so implementers put in place Exclusion Criteria to inform localities considering hosting a repository that the presence of certain site characteristics posed formidable, if not insurmountable, challenges to developing a facility.

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[73] The disposal concept proposed by the Chinese is similar to the Swedish KBS-3 approach, except that a steel canister substitutes for the copper one.

[74] Work in Xinjiang Province has been suspended.

[75] Sites in salt are not being considered because the mineral is considered to be a valuable resource.

[76] Specific site-suitability criteria are under preparation.

Figure 14. Prospective setting for a repository in China (Based on Wang 2014)

France

France was the first nation to experiment with a site-selection process in which volunteerism was an essential feature. The 1991 law, Research in Radioactive Waste Management, fundamentally restructured the country's approach to long-term management of HLW. The legislation established a three-pronged, 15-year research program. It gave the responsibility for conducting studies of transmutation/partitioning and long-term interim storage to the CEA. It assigned investigations for siting, designing, and operating a deep-mined, geologic repository to a new implementer, the public sector National Radioactive Waste Management Agency (ANDRA), which was made independent of the CEA. The law also established milestones for the waste-management program, including setting a 2006 date for the Parliament to review the status of the effort and to take the next step. Finally, the act sought to promote local consultation, dialogue, and monitoring through the creation of Local Information and Oversight Committees (CLIs). The 1991 law also created the National Commission for Evaluation (CNE) as a technical overseer of the research program.

Subsequent decrees specified how the legislation would be implemented. In 1993, the law's chief author, Christian Bataille, was appointed mediator and charged with creating a sustainable consensus and a responsible, democratic, and transparent process. He told *Le Monde*, "I propose to verify the geological feasibility of the projects that will be volunteered by interested regions, and not, as was done before, attempt to convince populations of the sites [that were] pre-selected for their geological qualities" (quoted in Mays 2004).

One of Bataille's first orders of business was to solicit from local elected officials expressions of interest to host one of the two legally required URLs; thirty positive responses were received. The Bureau of Geological and Mining Research screened the locations using Exclusion Criteria developed by the regulatory authority.[77] Potential sites in eight *départements* were identified. Bataille conducted well-publicized meetings in those localities, some of which subsequently decided to withdraw. Ultimately, four volunteer communities remained; each recognized that, if the geology was favorable, they could very well end up hosting not only a laboratory but also a disposal facility. Their locations are shown in Figure 15.

Figure 15. Potential sites for an underground research laboratory in France (Source: ANDRA 2013)

Because the two sites in the northeastern part of the country overlay a single argillite formation, ANDRA decided to construct a URL along the border between the two *départements* (Meuse and Haute-Marne) near the community of Bure. Another clay site, Gard, in the south was eliminated ostensibly for technical reasons. It was located just seven kilometers from the French nuclear complex at Marcoule but nonetheless aroused strong opposition from local winegrowers.[78]

The fourth potential site was located in west-central France in the Vienne *département*. That site sat on top of a granite formation. ANDRA planned to construct a second URL there. However, the CNE concluded that "the difficulties, in order to demonstrate convincingly the

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[77] "Basic Safety Rule, Number II.2.f," Direction de la Sûreté des Installations Nucléaires, June 10, 1991. These requirements were virtually identical to the recommendations advanced by Goguel's group.

[78] The winegrowers feared that a "stigma effect" would be attached to their product. The political consensus Bataille had hoped to form proved to be unsustainable. This stigma effect is discussed in greater detail in the section on the Social Acceptability Filter. See Barthe and Mays 2001:423-427.

feasibility of a repository on this particular site, are much greater than on the other sites … [and that] the assessment of this site leads us to outline the existence of negative aspects that appear today to be unavoidable" (CNE 1997). Subsequently, the site was officially rejected. However, because the 1991 law envisioned a URL constructed in granite, an extensive effort, ultimately unsuccessful, was initiated to find another volunteer site in crystalline rock. The story of that attempt is described in Box 7.[79]

> The so-called Granite Mission, composed of three senior civil servants, was chartered by Government in 1999. It differed from the Bataille effort in three important respects:
>
> - Out of concern that pressure was being put on poorer communities to accept a repository, the Granite Mission downplayed significantly the economic benefits that might accrue.
> - Rather than negotiating with local elected officials, the Granite Mission engaged local residents more proactively.
> - "Indisputable scientific bases," not just Exclusion Criteria, had to be used to identify potential sites.
>
> Once again, the Bureau of Geological and Mining Research identified 15 extensive granitic zones in 15 *départements*, mainly in Brittany and central France. Under the aegis of ANDRA, a committee of national and international experts was constituted to advise the implementer on its geological exploration activities and to orient future reconnaissance and construction work on the site(s) selected (Le Bars 2000).
>
> As this report details in the section on the Social Acceptability Filter below, the mission's carefully orchestrated engagement strategy was undermined when senior officials in the Environment Ministry leaked the location of the potential sites to the press. Although the mission visited three départements, it was met with unrelenting opposition and boycotts and was forced to continue its consultations in Paris.
>
> One after another, towns and regions passed resolutions prohibiting the disposal of radioactive waste within their borders. In May 2001, barely a year after starting its work, the mission was terminated and disavowed by Government.

Box 7. Searching for a granite site in France

Japan

Perhaps with the French experience in mind, the Japanese Diet passed the Specified Radioactive Waste Final Disposal Act in 2000. Two years later, the government-run implementer, the Nuclear Waste Management Organization (NUMO) issued a blanket invitation to all the 3,239 Japanese municipalities to consider whether they would be willing to host a repository for HLW and SNF (NUMO 2002b).

NUMO described a selection process that would proceed through three stages. In the first stage, localities would volunteer to be evaluated as "preliminary investigation areas." To qualify, an area could not fail any of four requirements set forth in the Exclusion Criteria (NUMO 2002a:5):

- There should be no records of significant movement in geological formations due to earthquake or fault activity, igneous activity, uplift, erosion, and other natural phenomena.
- The possibility of significant movement in the future due to earthquake or fault activity, igneous activity, erosion, and other natural phenomena should be small.

[79] This discussion draws heavily on Mays 2004.

- There should be no record of unconsolidated deposits that have been deposited during the Quaternary Period (i.e., in the past 1.7 million years).
- There should be no record of economically valuable mineral resources.

Sites that passed would then be assessed against more detailed "national evaluation factors" and "site-specific evaluation factors" (NUMO 2004).

To date, no community has agreed to participate in the site-selection process. By 2013, the Japanese Government decided to abandon the process created in 2000. In May 2015, the government approved a new approach. NUMO would no longer adopt a reactive stance. Instead, the government would nominate multiple suitable areas based on site-suitability criteria crafted by an expert group empaneled by the Ministry of Economy, Trade, and Industry (METI) (Nuclear Fuel 2015).

United Kingdom

In the United Kingdom, a five-year public consultation effort culminated with a Government *White Paper* adopting the "Managing Radioactive Waste Safely" (MRWS) program (DEFRA 2008b). A six-stage process was planned, which was initiated with invitations to communities to express an interest in hosting a deep-mined, geologic repository for HLW and SNF. At Stage 2, a "subsurface suitability" test would be applied to eliminate volunteers that controlled technically suspect areas. These Exclusion Criteria were drafted, more or less in parallel, by two Government-appointed groups of scientists (DEFRA 2007).[80]

The list of requirements included in the Exclusion Criteria that the two groups recommended contains few, if any, surprises:

- The absence of earthquakes and faults, uplift, erosion, and other geohazards, including those linked with future climate and environmental changes
- The absence of exploitable groundwater resources and specific complex or dynamic hydrogeological environments
- The absence of specific natural resources, including coal, oil, gas, geothermal energy, and metalliferous ores

By 2009, one county council (Cumbria) and two borough councils (Allerdale and Copeland) in West Cumbria, England, where the nuclear facility at Sellafield is located, had expressed an interest in hosting a repository, thereby triggering Stage 3. The British Geological Survey (BGS) concluded in 2010 that, within West Cumbria, at least some sites—unspecified—would pass the three exclusionary tests (BGS 2010:1-5). In January 2013, however, the Cumbria County Council voted to withdraw from the MRWS process, bringing it to a halt.

In the wake of this collapse, Government announced in July 2014 that it was modifying its site-selection strategy and moving away from an approach that relied solely on Exclusion Criteria to one that appeared to rely more on Generic Criteria (DECC 2014c). These will be drafted by the implementer with advice from the BGS and scrutinized by the implementer's technical overseer, the Committee on Radioactive Waste Management. An independent review panel established by the Geological Society will evaluate the new site-suitability criteria, which will be the subject of a public consultation.

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[80] Originally the governments of England, Scotland, Wales, and Northern Ireland subscribed to the MRWS process. Subsequently, after a change in government, Scotland withdrew. Scotland does not support any attempt to develop a repository in that country. Wales has taken a wait-and-see stance.

Canada

In 2002, the Canadian Parliament gave the responsibility to implement a nuclear waste-management program to what became the utility-owned implementer, the Nuclear Waste Management Organization (NWMO). In 2007, the Government of Canada accepted NWMO's recommendation to launch the Adaptive Phased Management program for siting a repository. Canadians are "committed to seeking an informed, willing community to host the long-term management facility. … It is against the backdrop of the community's own vision for its future that we will proceed" (NWMO 2005:40).

In 2009, NWMO released a draft nine-step process for selecting a repository site (NWMO 2009a).[81] NWMO's Exclusion Criteria were substantially more nuanced and comprehensive than the ones adopted in other nations. In addition to the requirements pertaining to the availability of land, the absence of groundwater and natural resources, and a location outside of protected areas and parks, NWMO maintained that the site must "not be located in areas with known geological and hydrogeological features that would prevent the site from being safe" (NWMO 2010:30). NWMO identified six technical factors affecting safety:

- Containment and isolation characteristics of the host rock
- Long-term stability of the site
- Repository construction, operation, and closure
- Human intrusion
- Site-characterization challenges
- Transportation

But rather than leaving these requirements ill-defined and opaque, NMWO specified at least one "performance objective" and several "evaluation factors to be considered" for each factor. NWMO emphasized that its site-suitability criteria "were selected in order to ensure that the requirements of Canadian regulators, as outlined in legislation and guidance documents, will be addressed throughout the site assessment process" (NWMO 2010:32).[82]

NWMO is unique among implementers that have articulated an explicit site-selection strategy. In addition to the six technical factors, NWMO identified five factors that "go beyond safety" to consider the well-being of the community and its neighbors. These factors include:

- Social, economic, and cultural effects
- Long-term sustainability
- Respect for ecologically sensitive areas
- Impacts on infrastructure
- Transportation effects

NWMO's public pronouncements and its subsequent decisions make clear that these "beyond safety" factors also could disqualify an otherwise technically suitable site.

Twenty-two localities initially expressed interest in learning more about the Adaptive Phased Management process and obtaining a fuller understanding of what hosting a

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[81] After receiving public comment, NWMO finalized its site-selection process a year later (NWMO 2010).

[82] The Canadian site-suitability criteria are described in Appendix 8.

repository might entail.[83] Based strictly on the technical Exclusion Criteria, NWMO suspended studies in one community, Red Rock, Ontario, in 2011. The locations of the remaining 21 communities that have expressed an interest in learning more about hosting a deep-mined, geologic repository are shown in Figure 16. These sites sit on top of both crystalline and sedimentary rock formations.

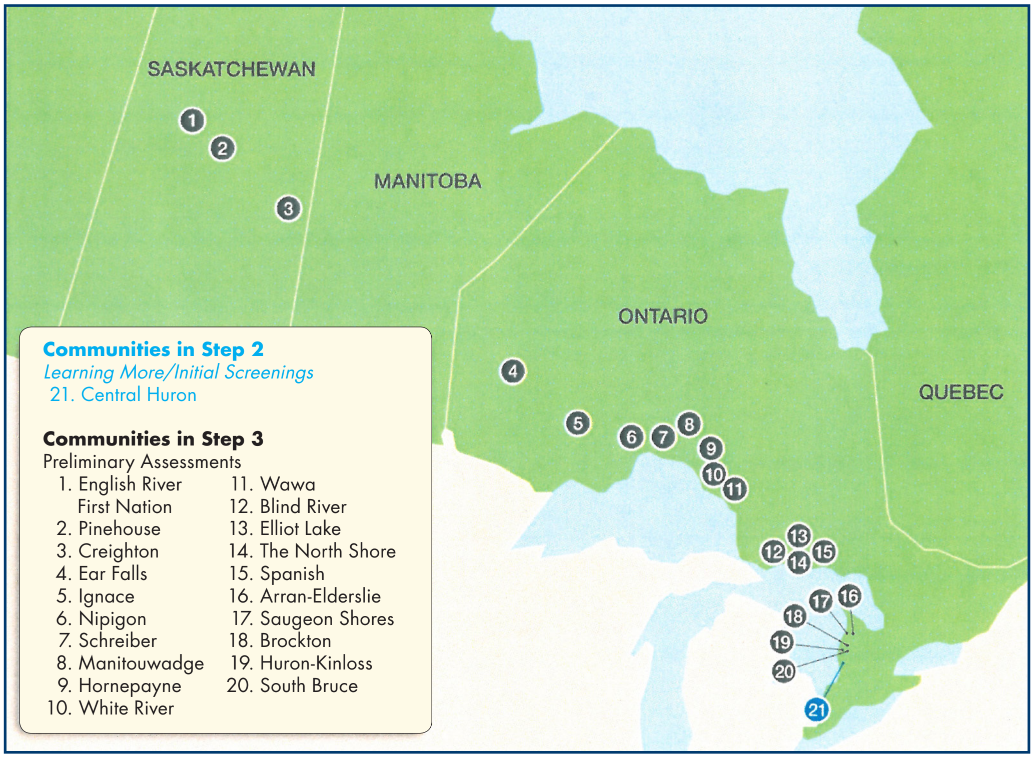

Figure 16. Communities interested in learning more about the implications of hosting a deep-mined, geologic repository in Canada (Source: NWMO 2013)

Under the terms of the Adaptive Phased Management program, the 21 communities moved into Step 3, Preliminary Assessment, which is divided into two phases. In both phases, four fundamental questions are posed:

- Is there potential to find a safe site?
- Is there potential to foster the well-being of the community through the implementation of the project, and what might need to be put in place to ensure this outcome?
- Is there potential for citizens to continue to be interested in exploring this project through subsequent steps in the site-selection process?
- Is there potential to foster the well-being of the surrounding area and to establish the foundation to move forward with the project?

Assessments undertaken in the second phase build on those conducted in the first, expanding the evaluations based on the available literature to include field studies and eventually borehole investigations as well as more detailed exploration of the potential to

[83] So great was the expressed interest that in September 2012, NWMO announced a suspension of additional expressions of interest (NWMO 2012).

foster well-being through the project in the community and surrounding areas (NWMO 2013). The structure of Phase 1 Preliminary Assessment is presented in Figure 17.

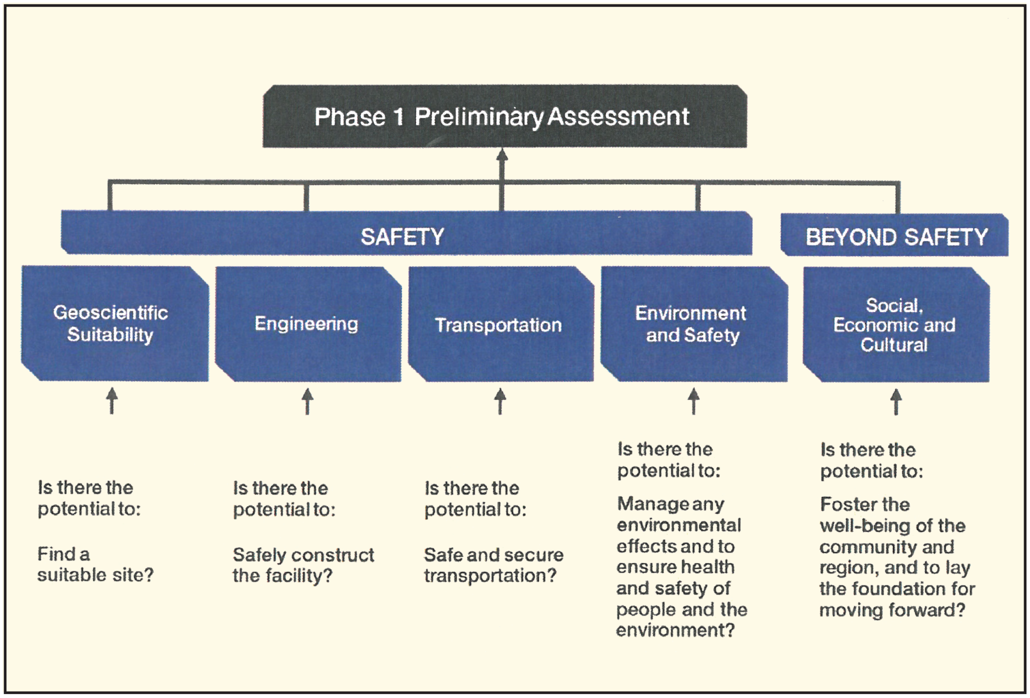

Figure 17. Structure of Phase 1 Preliminary Assessment under Canada's Adaptive Phased Management site-selection process (Source: NWMO 2013)

In November 2013, NWMO completed Phase 1 Preliminary Assessments at eight communities: Creighton, Ear Falls, English River First Nation, Hornepayne, Ignace, Pinehouse, Schreiber, and Wawa. NWMO concluded that all of the communities satisfied the requirements for engineering, transportation, and environmental protection during construction and operation. The jurisdictions differed, however, in terms of geoscientific suitability and projected community well-being during the implementation of the project. Consequently, only four communities—Creighton, Hornepayne, Ignace, and Schreiber—moved into Phase 2.[84] Importantly, NWMO emphasized that this determination does not necessarily confirm any of the communities "as suitable for hosting" a repository (NWMO 2013:21).

In January 2014, NWMO informed two additional communities—Arran-Elderslie and Saugeen Shores—that "its studies were concluded" and that it "will work closely with [them] to assist [their] transition out of the siting process."[85] In June 2014, the Township of Nipigon withdrew from the siting process after NWMO informed its mayor about the presence of "substantial geological uncertainties" and evidence suggesting that the "values and aspirations" of the community might not be aligned with the development of a

[84] NWMO's discussion of this decision appears to illustrate its sensitivity to community reactions. Not until the 20th page of a 27-page document does the reader learn which communities advanced into Phase 2. The four localities that did not move forward are never explicitly named. Moreover, NWMO avoids discussing beyond generalities the specific reasons for why a community did not remain in the siting process.

[85] Letter from Kathryn Shaver, Vice President, APM Public Engagement and Site Selection, to Paul Eagleson, Mayor of the Municipality of Arran-Elderslie, and to Mike Smith, Mayor of the Township of Saugeen Shores, January 16, 2014.

repository.[86] In December 2014, Phase 1 Preliminary Assessments were concluded in three communities in Bruce County. Two of them—Huron-Kinloss and South Bruce—passed into the next phase. The site at Brockton did not (NWMO 2014). In the following month, NWMO determined that four sites—Blind River, Elliot Lake, Manitouwadge, and White River—had a strong potential for meeting the site-selection requirements. Sites at Spanish and North Shore did not (NWMO 2015). In March 2015, NWMO informed the mayors of the Town of Creighton and the Township of Schreiber that geoscientific investigations undertaken as part of Phase 2 Preliminary Assessments "reduced the likelihood of finding a suitable repository site" in their areas.[87] As of May 2015, nine communities, all in Ontario, remain involved in Canada's site-selection process. Importantly, none of the communities that are no longer involved chose on their own volition to withdraw. Table 6 summarizes the decisions that have been taken as of May 2015.

Community	Phase One	Phase Two
English River First Nation	November 2013	
Pinehouse	November 2013	
Creighton	November 2013	March 2015
Ear Falls	November 2013	
Ignace	November 2013	March 2015
Nipigon	June 2014	
Schreiber	November 2013	March 2015
Manitouwadge	January 2015	
Hornepayne	November 2013	
White River	January 2015	
Wawa	November 2013	
Blind River	January 2015	
Elliot Lake	January 2015	
North Shore	January 2015	
Spanish	January 2015	
Arran-Elderslie	January 2014	
Saugeen Shores	January 2014	
Brockton	December 2014	
Huron-Kinloss	December 2014	
South Bruce	December 2014	
Central Huron		

Community continues to be evaluated
Community was dropped from further study
No decision has yet been made

Table 6. Results of Phase 1 and Phase 2 Preliminary Assessments for communities participating in Canada's Adaptive Phased Management site-selection process

[86] Letter from Kathryn Shaver, Vice President, APM Public Engagement and Site Selection, to Richard Harvey, Mayor of the Township of Nipigon, June 11, 2014.

[87] Letter from Kathryn Shaver, Vice President, APM Public Engagement and Site Selection, to Bruce Fidler, Mayor of the Town of Creighton, and to Mark Figliomeni, Mayor of the Township of Schreiber, March 2, 2015.

Designing and Developing Technical Suitability Filters to Identify Prospective Settings and Potential Sites

Developing a deep-mined, geologic repository at any location inevitably carries with it both benefits and costs. Consequently, siting is the step in the repository-development process that is most likely to spark initial public interest and involvement. As one IAEA report put it: "Members of the general public and representatives of local communities recognize that they have a clear stake in the outcomes of [siting] decisions and almost always seek to have their views taken into account by the policy elites" (IAEA 2007:40). For this reason, it is instructive to examine how the site-suitability criteria, which strongly structure the entire siting process, came into force.

Implementers enlist scientific and engineering specialists to craft site-suitability criteria. The logic of that choice is indisputable. If the ultimate desired outcome of any site-selection process is the development of a facility, whose long-term performance must satisfy regulatory constraints, then technical expertise is essential. But whose expertise counts?

Based on the historical record, implementers have almost always relied on their own expertise. Siting efforts in Sweden and Finland, for instance, have proceeded without formally adopted, predetermined criteria either for site suitability or site disqualification.[88] Instead, internally directed scientific and engineering judgments were applied by SKB and Posiva Oy to weigh the merits of a particular site at the screening stage. Early attempts to devise siting rules in France (Goguel; Bureau of Geological and Mining Research; Granite Mission), in Germany (Institute of Soil Research; KEWA; State of Lower Saxony), in Japan, in Switzerland (Project Gewähr), and in the United States (AEC; ERDA) lacked any element of what today would be called transparency. The efforts were organized by the implementer, early versions were revised based solely on the implementer's views, and the final product was released by the implementer to an unaware and often unsuspecting public as *dictum*.[89]

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

United Kingdom

Several exceptions to this pattern, however, can be found in the historical record. In the United Kingdom, the implementer proposed Exclusionary Criteria in 2007 and solicited public comments; nearly 80 were received. Over 60 percent of respondents supported the proposed criteria, and 13 percent opposed them (DEFRA 2008a:22).[90] Asked by the implementer to reflect on the public input, the chairmen of the two expert advisory groups that originally drafted the criteria observed: "Our conclusions are that the criteria we recommended should stand, that further criteria are unnecessary at this initial stage of site selec-

[88] This is true even though vague statements about suitability can be found in each country's nuclear legislation, rules, and regulatory guidance.

[89] In addition to the experience in the United Kingdom, Canada, and the United States, all of which are discussed below, the Swiss government conducted an extensive public review of the Sectoral Plan (SFOE 2008). That review was carried out over a two-year period and included the publication of three drafts for comments, two sets of formal consultations, two workshops involving interested and affected parties, and public focus groups. The drafts and the public comments are not available, so it is not possible to draw even tentative conclusions about the thrust of the comments or whether they influenced the final version of the Sectoral Plan.

[90] It is difficult to discern any particular pattern in the responses. In particular, the commenters were not seeking to tighten the Exclusionary Criteria to eliminate locations nearby.

tion, and that we see no need for any fundamental change to the way in which our original recommendations were set out" (quoted in DEFRA 2008b:73). Government agreed.

Canada

Beginning in 2008, the Canadian implementer engaged interested and affected parties to create a process for siting a deep-mined, geologic repository for HLW and SNF. It published a draft approach (NWMO 2009a). Public information sessions were held in 17 regional centers; multi-party dialogues were convened in four locations; and citizen panels were brought together in Toronto and Ottawa. Special efforts were made to engage Aboriginal organizations in four provinces. Finally, social media and telephone surveys were used to elicit views of a broad section of the Canadian public.

A report on these outreach activities describes the wide range of comments that NWMO received (NWMO 2009b). Almost entirely the comments focus on the *design* of the process—who should be involved, when decisions should be made to screen out communities, and how to ensure that regulatory expectations and requirements are met. NWMO states that this extensive input resulted in significant changes to the proposed process. Perhaps because very few responses were received on the subject, only cosmetic—not substantive—changes were made to a core element of the process: the site-suitability criteria.[91]

Although the efforts by the British and the Canadians to incorporate public comments when Exclusion Criteria were being established had a negligible impact, the situation was strikingly different—at least with respect to form and structure if not substance—in the United States.

United States

One important difference between the United States and other countries in terms of the development of site-suitability criteria was that Congress was heavily involved.[92] It prescribed a set of nine considerations that DOE had to incorporate into its *Siting Guidelines*.[93] As this report notes above, these ranged from hydrology and geophysics to proximity to water supplies. Congress even specified that a site would be disqualified if any surface facility was located too close to a population center, more specifically, "adjacent to an area 1 mile by 1 mile having a population of not less than 1,000 individuals."

A second difference was that DOE put in place a comprehensive process to engage interested and affected parties in developing the *Siting Guidelines*. As this report describes above, on February 7, 1983, exactly two months after the NWPA became law, DOE published for public comment "Proposed General Guidelines for Recommendation of Repository Sites" (DOE 1983a).[94] In addition to soliciting written responses, over the course of ten months DOE held more than two dozen meetings with the general public and with officials from the affected states.[95]

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91 Compare NWMO 2009a:28-30 with NWMO 2010:33-35.

92 This involvement will be discussed in greater detail in the section of this report describing the interdependency of technical site-suitability criteria and political influence.

93 NWPA Section 112(a).

94 Between February and November 1983, at least six consultations were held between DOE and interested federal agencies. The public records that document those exchanges are incomplete, but what is available suggests that the agencies focused on relatively narrow technical points. See, for example, letter from D.G. Frederick, Associate Director, U.S. Geological Survey, to J. William Bennett, DOE, October 21, 1983. Moreover, from the moment that the drafting of the guidelines began, DOE headquarters also held ongoing and sometimes tense negotiations with the four field offices and their supporting contractor organizations that were carrying out the technical investigations related to siting a repository.

95 For a fuller description of DOE's engagement efforts, see DOE 1984b:47, 718-47, 719.

DOE received a flood of public comments.[96] Most of them came from the six state governments where the nine potentially acceptable sites for the first repository were located and from the 17 other state governments where sites were identified in the Second Round.

The state governments, nongovernmental organizations, and individual members of the public raised wide-ranging concerns with the first draft of the guidelines. DOE responded by circulating a second draft in May 1983 (DOE 1983c). In it, DOE fundamentally restructured its proposed rule, adding the implementation guidelines and separating the technical criteria into two distinct sets—preclosure and postclosure.[97]

Ultimately, however, DOE decided to adopt only a very small portion of the advice it received, and the modifications that it accepted were insubstantial compared to the ones that it rejected (DOE 1983d; DOE 1984b).[98] One notable exception to this general pattern was DOE's agreement with the states that "engineered barriers should not be allowed to compensate for geologic deficiencies" [DOE 1983d:18-19; DOE 1984c:960.3-1-5(e)].

Among the more significant revisions sought by states and other interested and affected parties, but not embraced by DOE, were the following:

- Make the technical criteria less general and more specific.[99]
- Revise the implementation guideline to align it with the methodology proposed by 14 states and one Indian Nation.[100]
- Provide a rank order for each of the technical criteria.[101]
- Make the technical criteria more specific, including adding a "disqualifying condition" for every "qualifying condition."[102]

Although DOE provided an exhaustive rationale for why it (mostly) rejected the suggestions made by those commenting on the various drafts, its reasoning masks the fundamental conflict that emerged between the implementer and the interested and affected parties.[103] On the one hand, because the stakes in making siting choices were so high, state governments in particular felt compelled to minimize the discretion of the implementer and to ensure that it was exercised as "objectively" as possible. On the other, DOE believed that, as the expert agency, Congress had given it the legitimate authority and discretion to make the siting choice. These two perspectives are captured well in the quotations below.

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[96] In the first three months following the first publication of the draft guidelines, DOE heard from 414 people at public meetings held in Washington, DC, New Orleans, Seattle, and Salt Lake City. In addition, more than 119 individuals and organizations sent in written comments, which, if printed out, would fill nearly 1,000 pages.

[97] Additional drafts were circulated in June and September 1983. These contained modest changes from the May draft.

[98] DOE 1983d was never publicly released. A later discussion of why some comments were adopted and others were not was published as DOE 1984b. That document incorporates the same logic as the earlier draft.

[99] See, for example, "Report of the Hearing Panel, Washington, DC, March 10, 1983."

[100] See, for example, letter from Rudy Perpich, Governor of Minnesota, to Donald Hodel, Secretary of Energy, September 6, 1983.

[101] See, for example, letter from Richard Riley, Governor of South Carolina, to Robert Morgan, DOE Project Director, April 12, 1983.

[102] See, for example, letter from Robert Loux, Administrator, Nuclear Waste Evaluation Program, State of Nevada, to Critz George, DOE Office of Nuclear Waste Management, June 8, 1983.

[103] The State of Nevada challenged the guidelines in *Nevada v. Watkins*, 939 F.2d 710. The Court of Appeals for the Ninth Circuit ruled that the challenge was not ripe because the guidelines did not represent "final agency action."

> *From the public:* "There are no quantitative limits or values, no weighting or rank ordering, or other prioritization of the various factors. This maximizes the likelihood of subjectivity and choices based primarily on non-relevant factors. Indeed, the guidelines seem to have been designed so that no sites can be excluded on the basis of them."[104]

> *From DOE:* "The Department believes that no decision methodology, however sophisticated, could be sufficiently comprehensive to remove the necessity for Federal officials in close consultation with States and affected Indian tribes to exercise judgment and discretion in making decisions in the future. … It is this openness and consultation that can assure objectivity to these important decisions."[105]

The NWPA provided that NRC must concur with DOE's *Siting Guidelines* before it could take effect.[106] If DOE could under law reject most of the public input it received on the proposed guidelines, it was more constrained in dismissing the views of its regulator. On November 23, 1983, DOE forwarded to NRC the latest draft of its *Siting Guidelines* and asked that it be approved. Seven weeks later, the Commission held a public hearing where interested and affected parties were provided an opportunity to make their positions known. In DOE's opinion, "A serious and deliberate consideration of these issues [raised at the hearing] and review of the siting guidelines in light of those issues reaffirmed our conclusion that such issues had been fully considered previously …" (DOE 1984a:2).

NRC staff disagreed (NRC 1984). In a March 9, 1984, preliminary decision, the Commission adopted the stance of its staff and stated that it would concur, provided DOE met seven conditions. Two were jurisdictional, a third called for tighter language rejecting the use of an engineered barrier to compensate for geologic deficiencies, and a fourth sought relatively modest substantive changes in language to achieve greater consistency between NRC's licensing regulation, 10CFR60, and the *Siting Guidelines*.[107] DOE had no qualms in accepting the first four conditions.

Acceding to the remaining three conditions, however, would have required DOE to make significant modifications to the guidelines.

- Specification in greater detail how the guidelines would be applied at each siting stage
- Supplementation of the guidelines to indicate the kinds of information necessary for DOE to make decisions on nominating five sites and recommending three sites for characterization
- Specification of additional disqualifying conditions for four postclosure technical criteria[108] and four preclosure technical criteria

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[104] Letter from Susan Williams, Attorney, Fried, Frank, Harris, Shriver, and Kampelman, representing the Nez Perce Tribe of Idaho to Robert Morgan, Project Director, DOE Office of Civilian Radioactive Waste Management, April 6, 1983.

[105] Letter from Robert Morgan, Acting Director, DOE Office of Civilian Radioactive Waste Management, to Richard Bryan, Governor of Nevada, November 25, 1983.

[106] Section 112(a).

[107] These dealt with groundwater travel time, effective porosity, hydrology affecting a potential repository located in the unsaturated zone, groundwater hardness, disturbed zone, sustained erosion, significant subsurface mining, alignment of disturbed processes with NRC's anticipated and unanticipated events, and dissolution at a potential site.

[108] These were natural resources, hydrology, geophysics, and seismic activity.

These conditions, which partially responded to the concerns of the 22 state governments, can reasonably be interpreted as an attempt by NRC to rein in DOE's discretion.

After a month of internal debate and discussion, the responsible DOE official informed NRC that the reasons for seeking to impose the three conditions lacked an "appropriate justification" and were of "questionable validity."[109] Yet, DOE had to find a way to at least minimally address the regulator's demands. The Department eventually did so. In retrospect, however, the changes do not appear to strongly constrain DOE's discretion. NRC ultimately accepted DOE's somewhat modified language.

Technical Suitability Filters to identify prospective settings and potential sites have a profound influence on the structure of the entire siting process; they determine which pieces of real estate are to be considered and which pieces are no longer on the table. It is noteworthy, then, how little impact the expertise offered by interested and affected parties has had in establishing the filters. Almost without exception, that task is left exclusively to technical experts working for the implementer. Notably, when one implementer, DOE, sought extensively to engage outsiders, it declined to accept most of the opposing technical narratives. Even faced with a legal requirement for regulatory concurrence, it fought hard and largely succeeded in retaining as much discretion as possible. An open question therefore poses itself: is this rational organizational behavior viable over the long term?

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

Passing Potential Sites Through the Final Technical Suitability Filter

Once the initial screening process has been completed, that is, prospective settings and/or potential sites have been formally identified (and socially accepted), they will need to pass through a more detailed, and perhaps more stringent, Technical Suitability Filter. Table 7 on the following pages summarizes the siting efforts discussed above and highlights the nine instances where a final Technical Suitability Filter was applied, either partially or fully. This subdivision describes and analyzes seven of the nine cases. Because the ordering of the filters shifted in the later stages of the siting processes that led to the selection WIPP site and the site for the proposed Yucca Mountain repository, those stories will be told in the next section of this report, which considers the Social Acceptability Filter.

The discussion of the remaining seven cases is organized around the three types of site-suitability criteria presented above:[110]

- Host-Rock-Specific Criteria (Single Disposal Concept)
- Generic Criteria (Multiple Disposal Concepts)
- Exclusion Criteria (Single and Multiple Disposal Concepts)

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[109] Letter from Michael Lawrence, Acting Director, Office of Civilian Radioactive Waste Management, to Secretary, Nuclear Regulatory Commission, April 6, 1984, 2.

[110] The discussions of Host-Rock-Specific Criteria and Generic Criteria also include a description of how the implementer applied Exclusion Criteria. The discussion of Exclusion Criteria is limited to those instances where the implementer provided guidance to communities interested in possibly volunteering to host a repository.

Country	Initial Site Screening	Application of the Final Technical Suitability Filter	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 (1989-present)			Ongoing
Finland			
Site selection for a deep-mined, geologic repository (1982-present)			Repository site in the community of Eurajoki was selected.
France			
Site investigations by the Atomic Energy Commission (1987-1990) to determine the technical suitability of sites in four different host rocks			Terminated because of public and political opposition
Site selection for an underground research laboratory (1993-2006) in granite and clay in a volunteer community			Repository site in the Meuse/Haute-Marne ***département*** was selected.
The Granite Mission (1999-2001) sought to find a volunteer community willing to host an underground research laboratory.			Terminated because of public and political opposition

Activity completed — Activity ended before completion or is still in progress — Final Technical Suitability Filter not applied

Table 7. From initial site screening to the application of the final Technical Suitability Filter

Country	Initial Site Screening	Application of the Final Technical Suitability Filter	Outcome
Germany			
The 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 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
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.

Activity completed   Activity ended before completion or is still in progress   Final Technical Suitability Filter not applied

Table 7. From initial site screening to the application of the final Technical Suitability Filter (continued)

Country	Initial Site Screening	Application of the Final Technical Suitability Filter	Outcome
Switzerland[1]			
Project Gewähr attempted to identify a site in granite for a deep-mined, geologic repository (1978-2004).			Terminated because of the difficulty identifying a site where the concept could be implemented.
The Swiss Government launches the Sectoral Plan aimed at finding a site for a deep-mined, geologic repository in Opalinus clay (2008-present).			Ongoing
United Kingdom			
The Managing Radioactive Waste Safely program sought volunteer communities interested in hosting a deep-mined, geologic repository (2008-2013).			Terminated because Cumbria County Council voted to withdraw from the process
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.

Activity completed　Activity ended before completion or is still in progress　Final Technical Suitability Filter not applied

[1]The documentation of Nagra's decision to recommend three potential sites for an HLW and SNF repository and the documentation of the Swiss Federal Office of Energy's decision to approve continued work at the three sites are not available in English.

Table 7. From initial site screening to the application of the final Technical Suitability Filter (continued)

Country	Initial Site Screening	Application of the Final Technical Suitability Filter	Outcome
United States *continued*			
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 approves the selection of that site for development as a repository.			Congress restricted site characterization to the Yucca Mountain site in Nevada.
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. The 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, EPA certified that WIPP complied with all applicable federal waste disposal regulations.

Activity completed — Activity ended before completion or is still in progress — Final Technical Suitability Filter not applied

Table 7. From initial site screening to the application of the final Technical Suitability Filter (continued)

Host-Rock-Specific Criteria (Single Disposal Concept)

United States

The AEC's screening process in the late 1960s and early 1970s led it to prospective settings in central Kansas, southeastern Michigan, and southwestern New York. Although each of the three areas met the minimal requirements for a repository, central Kansas soon became the leading contender because the depth to the disposal horizon was shallower, thereby making construction easier; because the thickness and areal extent of the formation were greater; because the region was in seismic risk zone 1 (expected minor damage); and because considerable experimental work had already been conducted (Lomenick 1996:14).

In Lyons, located about 80 miles northwest of Wichita, an excavation owned by the Carey Salt Mining Company was ultimately selected as the site for a demonstration salt repository (AEC 1970; AEC 1971b).[111] In addition to satisfying the Host-Rock-Specific Criteria, other considerations appeared to make that location appear uniquely suitable: (1) it was the only available, accessible, nonproducing mine in the three areas initially evaluated; (2) it was served by two railroads and a major highway; (3) ORNL had studied the formation as part of its Project Salt Vault investigation; and (4) a favorable reception from local and state authorities was expected.[112]

In November 1970, the AEC released a draft EIS evaluating the effects of developing a deep-mined, geologic repository at the Lyons site. At the same time, the AEC circulated a study undertaken by the NAS.[113] The report noted the need for additional investigations but concluded that "based on the research and development performed to date, the Committee does not anticipate any insurmountable problem [with the Lyons site]" (NAS 1970:4).

Comments on the draft EIS from Kansas office holders, the governor, and both senators were cautiously skeptical; comments from federal establishment; the Department of the Interior; the EPA; the Department of Health, Education, and Welfare; and individuals employed by the AEC's national laboratories were cautiously supportive.

A final EIS was released in June 1971 and was supplemented a month later (AEC 1971c; AEC 1971d). The final EIS, like the draft, focused almost exclusively on the effects of constructing and operating the facility. These effects, it concluded, would be minimal. So well-entrenched was the belief in the effectiveness of disposing of HLW in a salt formation that the long-term performance of the facility was discussed on a single page: "solid-state diffusion of plutonium" in salt was estimated to be no more than 25 centimeters in one million years. The prospects for enhancement of volatility of the isotopes by steam arising from the brine within the salt were considered very remote. Thus, through this environmental assessment process, the Lyons site passed through the final Technical Suitability Filter.

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111 The best discussion of the attempt to site a repository in Lyons, Kansas, can be found in De la Bruhèze 1992:139-178. Another source is Walker 2009:51-75.

112 The decision to develop a demonstration repository was precipitated by a fire at an AEC nuclear weapons facility, Rocky Flats. Waste material had been sent to the Idaho National Reactor Test Station for storage. Idaho's governor and senators extracted a commitment from the AEC to remove the material within a decade. This circumstance, coupled with the adoption of 10CFR50, Appendix F, which gave the responsibility for developing a repository to the Federal Government, undoubtedly accelerated the site-selection process (OTA 1985:Appendix A). Congress ratified the choice of Lyons in a provision creating a National Radwaste Repository Program as part of the Atomic Energy Authorization Act of 1972.

113 The AEC publicly maintained that it was proposing a "demonstration repository" and that its construction was predicated on future investigations to ascertain the site's suitability. Within the agency, however, there was little doubt that the site would ultimately be designated "as the initial Federal repository." See AEC 180-81, "Solid Radioactive Wastes: Salt Mine Storage," April 23, 1970.

Even before the final environmental statement was published, however, information came to light that demonstrated how cursory the AEC's site "characterization" had been. Solution mining adjacent to the Lyons site had created a large cavity that could potentially collapse, thereby threatening the integrity of the proposed repository; leaks had developed at the face of the Carey mine; the locations of the exploratory gas and oil boreholes were not fully known; and 175,000 gallons of water used for hydraulic fracturing in the area simply disappeared underground. Faced with these technical challenges, on September 30, 1971, the AEC's General Manager informed Congress that all work on the Lyons site was now in "abeyance."

Germany

As difficult as it was, at least the U.S. attempt to select a salt site at Lyons, Kansas, reached a definitive end. The situation in Germany is still evolving nearly 40 years after the Lower Saxony *Land* identified four potential sites for a repository that would be constructed as one element in a larger nuclear waste-management complex.

The Lower Saxony President, Ernst Albrecht, announced his government's site-selection decision in February 1977. The salt dome near Wahn was rejected because it was the location of an army base, and the one at Höfer was eliminated because it had been an active salt mine. In the choice between salt domes located at Lichtenhorst and Gorleben, the latter prevailed, notwithstanding concerns about its proximity to the then-East German border. (See Figure 7 on page 35.) Five months later, the Federal Government accepted the *Land*'s choice of a candidate site because no former mining activity or deep borehole drillings had taken place there; because the dome was large enough; because the dome was less than 400 meters below the surface; and because no usable resources, including groundwater, were threatened.

Passing the Gorleben site through the final Technical Suitability Filter, however, remains a work in progress. In the spring of 1977, hearings involving a wide range of international experts were held on whether the nuclear waste complex should be constructed. Two years later, the President announced that the reprocessing plant that was to be part of the nuclear waste-management complex "politically will not be accepted" but that the Gorleben site was still suitable for hosting a deep-mined, geologic repository. No final report supporting those conclusions has ever been released.

Surface-based geological investigations were conducted at the Gorleben site between 1979 and 1983. In 1981, the Federal Government held a public meeting to update the community about the progress of the technical studies. Two issues dominated. First, salt dissolution by flowing groundwater, subrosion, was discovered at the top of the formation. Second, preliminary results revealed the existence of the so-called Gorleben channel. This erosion channel of Quaternary age, which crossed the dome and cut locally into its body, is filled with sediments of much higher permeability than the salt. If the constituents of the waste reached the interface between the salt and overlying beds, the channel could cause accelerated radionuclide transport to the biosphere.

The government believed that those fast paths did not significantly degrade the ability of the Gorleben salt dome to isolate and contain radionuclides. Critical experts were given an opportunity to respond to the optimistic interpretations of these results. A second meeting a year later focused on the Gorleben channel and on the uncertainties related to modeling of radionuclide transport. Again, critics could present their own interpretation of the studies.

In 1983, the Physickalisch-Technische Bundesanstalt (PTB)—the forerunner to the Federal Office for Radiation Protection (BfS)—reported on the results of the surface-based investigations. The document acknowledged the safety significance of the Gorleben channel. But PTB concluded that the site had "Eignungshöffigkeit," that is, it exhibited a high likelihood of being suitable. The implementer's report aroused considerable controversy when it was presented at a third public meeting, where, unlike the previous two, formal critical responses were not permitted (Hocke and Renn 2009).[114]

The Federal Government approved underground explorations at the Gorleben site, beginning in 1985 with the sinking of two shafts and continuing, on and off, for 15 years. During that time, extensive studies were undertaken and analyses performed even as the political environment remained turbulent. In 1998, a coalition of the Social Democratic and Green parties gained the majority in the Bundestag. The newly formed government entered into negotiations with the nuclear industry, which, among other things, resulted in a ten-year moratorium on investigations at Gorleben. The moratorium was briefly lifted between 2010 and 2013 but was reimposed with the passage of the Repository Site Selection Act.[115] The 1983 PTB report remains the sole authoritative statement about whether the Gorleben site can pass successfully through the final Technical Suitability Filter.

Finland

Because of differences in the legal frameworks in Finland and Sweden, the Finnish implementer, Posiva Oy, ended up taking the first step. As this report discusses above, by 1987, five potential sites were identified, and a sixth was added when a new nuclear law was enacted in 1996. (See Figure 10 on page 39.) Carrying out detailed investigations at so many sites was seen as posing serious logistical, financial, and political challenges. So by the end of 1992, Posiva Oy sought to eliminate two or three from further investigation. The two main factors used to make that determination were:

- Sites with as simple a geology as possible needed to be chosen so that the uncertainties associated with the development of the safety case could be kept within acceptable limits. … A site with a simple geology would result in simpler site investigation and would simplify the presentation of the safety case.
- The [six] sites investigated tended to be so similar geologically that other factors needed to be introduced in order to choose between them. The factors that were thought to be of most interest in this regard were the impact on the local community and the potential supply of a local labor force. (McEwen and Äikäs 2000:10-11)

As a result of these considerations, two sites, Syyra and Veitsivaara, were eliminated in 1992 because those locations were considered too complex to investigate.

Using STUK's draft regulatory requirements, Posiva Oy performed assessments of the long-term safety of a repository developed at each of the four remaining sites: Hästholmen, Kivetty, Eurajoki (Olkiluoto on Figure 10), and Romuvaara. Deterministic

[114] Thirteen years later, BfS was still unwilling to make a definitive statement about its view about the suitability of Gorleben for disposing of HLW and SNF (BfS 1996). The furthest it has gone is to assert that the site is not unsuitable. But see BMWi 2008 for a more upbeat assessment of the suitability of the Gorleben site. That report, however, did not represent the position of the governing coalition.

[115] Under this law, Gorleben is to be maintained so that it might be considered as a potential repository site once a new siting process was established. As of May 2015, only the shafts are being maintained; the drifts, where the underground investigations took place, will eventually close as a result of salt creep due to the pressure of the overlying geology.

assessments of three reference scenarios were carried out using the framework shown in Figure 18 on the next page.

The primary conclusion of those evaluations was that, from the standpoint of postclosure safety, "all four candidate sites are suitable to host a repository for spent fuel. The safety assessments do not give reasons to reject any of them, neither do release and transport analyses of radionuclides provide firm grounds to rank one site above the others" (Posiva Oy 1999a:218).[116] In any event, as Figure 19 on page 77 shows, the maximum annual dose expected from a leaky canister is many orders of magnitude below the draft regulatory constraint of 0.1milliSieverts per year.

In 1999 as well, the implementer published an EIS comparing the four remaining sites using eight factors (Posiva Oy 1999b):

- Long-term safety
- Repository constructability
- Possibilities to expand the final disposal repository
- Operation of the final disposal facility
- Social acceptance
- Land use and environmental loading
- Infrastructure requirements
- Cost

Because Posiva Oy concluded that the relatively small differences in bedrock conditions among the four sites did not allow considerations of long-term safety to be of "overriding significance" in selecting a preferred site for repository development, the other seven dimensions came into play. Constructability and expansion possibilities proved not to be discriminating factors. As far as operational safety was concerned, the properties of the disposal site were not viewed as playing a significant role. To the extent that there were transportation differences among the sites, Eurajoki was to be preferred; more SNF would be generated at that location and thus would not have to be transported over long distances. Public opinion studies also indicated that social acceptance was higher in Hästholmen and Eurajoki, where the operation of nuclear power plants had produced tangible economic benefits and a reservoir of trust. But the potential for polarization was greater in the former community. The presence of nuclear facilities in the two communities meant that the land-use changes, environmental impacts, and infrastructure requirements would be lower than at either Romuvaara or Kivetty. Finally, given the uncertainties associated with projecting future costs, it was difficult to sustain a claim that developing a repository at one of the sites would be more or less expensive than at any other. Infrastructure savings in the two nuclear communities were likely to be negated by the lower costs of building a facility at the nonnuclear sites where the groundwater was less saline (Posiva Oy 1999b:183-187; McEwen and Äikäs 2000:188-189).[117]

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[116] The major difference discovered traces back to difference in the salinity of the groundwater between the two inland sites and the two coastal sites. According to Posiva Oy, the higher salinity at the coastal sites limits the bedrock volume available for final disposal. But proximity to the sea reduces the probability that radioactive substances would end up in people's food or drinking water in appreciable concentrations (Posiva Oy 1999b:137).

[117] In its review of the EIS and Posiva Oy's subsequent decision to select the Eurajoki site, the Finnish regulator, STUK, concurred with the implementer's choice (STUK 2000).

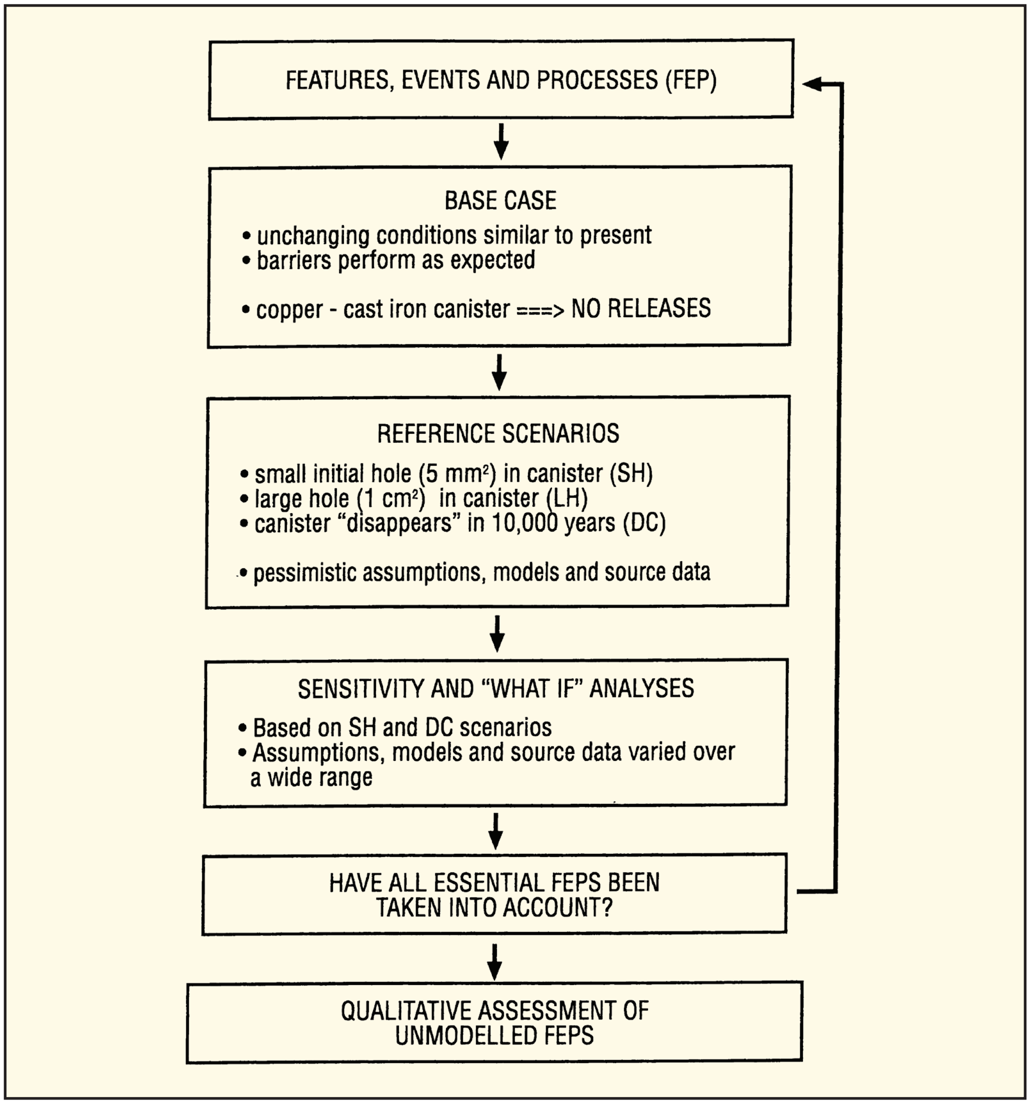
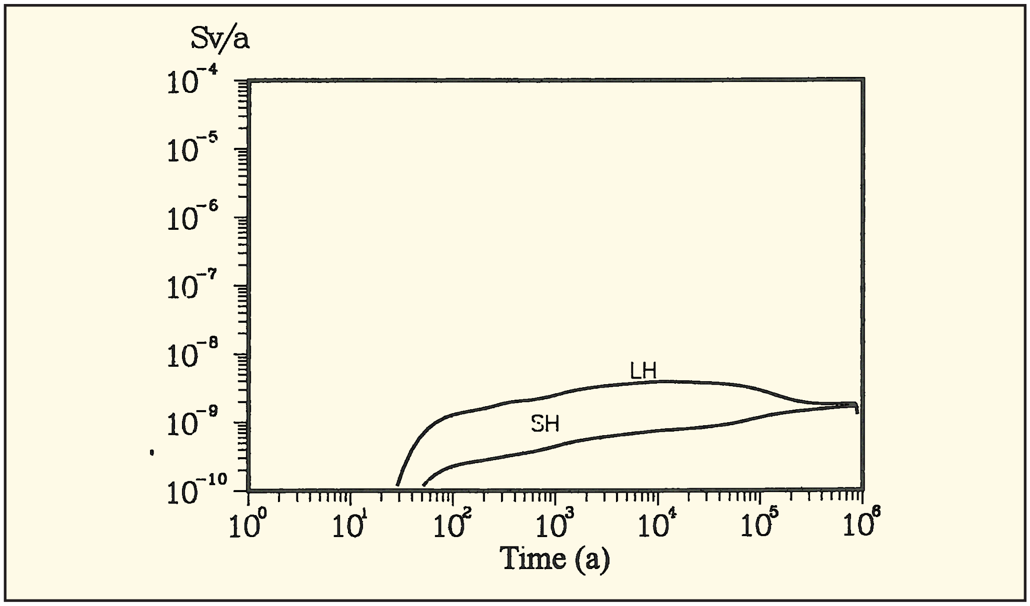


Figure 18. Structure of the safety analysis for the candidate sites in Finland (Source: Posiva 1999b)

Based on these assessments, Posiva Oy submitted an application to the Finnish Government for a Decision-in-Principle to approve the implementer's choice of Eurajoki as the location for the deep-mined, geologic repository for SNF, thereby passing the site through the final Technical Suitability Filter.

Sweden

Recall that the Swedish implementer, SKB, identified eight potential sites as a result of feasibility studies conducted from 1992-2000. (See Figure 9 on page 37.) Referenda held in Storuman in 1995 and in Malå in 1997 led the two municipalities to withdraw from the site-selection process. Early on, SKB determined that in Älvkarleby, geological conditions were too difficult to evaluate and that "the probability of finding sufficient volumes of suitable bedrock was too low to warrant further investigations" (SKB 2011a:22). In 2001, the Nyköping municipality also decided to drop out, as did Tierp a year later. Hultsfred, an inland municipality without any connection to SKB's maritime transportation network, was relegated to back-up status. Thus, in quick order, the eight prospective sites were reduced to two candidate sites—Forsmark and Laxemar in the nuclear communities



SH = Small hole in the waste package LH = Large hole in the waste package

Figure 19. Results of the safety analyses for the candidate sites in Finland (Source: Posiva Oy 1999a)

of Östhammar and Oskarshamn, respectively.[118] Detailed site investigations took place between 2002 and 2009.

SKB never detailed *a priori* precisely what requirements would have to be satisfied to pass candidate sites through the Technical Suitability Filter. Instead, SKB advanced four broad considerations (Swedish National Council 2008:29-43):

- Safety-related site characteristics
- Technology of execution
- Health and environmental impacts
- Societal resources

SKB based its site-selection strategy on two decision rules that conceptually were quite similar to those advanced by Posiva Oy (SKB 2011a:4):

- The site that offers the best prospects for achieving long-term safety in practice will be selected.
- If no decisive difference is found between the sites in terms of their prospects for achieving long-term safety, the site that is judged to be the most favorable from other aspects for accomplishing the final repository project will be selected.

On June 3, 2009, SKB's President (right in Figure 20 on page 78), accompanied by the mayors of Östhammar (center) and Oskarshamn, stepped off the *Sigyn* and announced that "the rocks had spoken." Forsmark had been chosen.[119]

[118] Initially SKB investigated the area of Simpevar in Oskarshamn. When its rock appeared unsatisfactory, the area of Laxemar was studied.

[119] "The site selection was made when the analyses on which this study is based (and comparisons with respect to other factors …) had come to the point where it was clear that Forsmark was the more suitable site and that the remaining analysis work could not change this outcome" (SKB 2011a:52).

Figure 20. Announcement of the selection of the Forsmark site. (Courtesy of SKB. Photo: Patrik Lundin)

At that time, the detailed technical basis for that choice was not released. But, shortly thereafter, a comparative safety analysis concluded:

> [T]here are a number of safety-related site characteristics for which the analyses do not show any decisive differences, in terms of implications on safety, between the sites at Forsmark and Laxemar. However, the frequency of water conducting fractures at repository depth is much larger at Laxemar than at Forsmark. This difference, in turn, affects the future stability of current favorable groundwater composition, which combined with the much higher flows at Laxemar would lead to a breach in the safety functions for the buffer and the canister for many more deposition positions at Laxemar than at Forsmark. Thereby the calculated risk for Forsmark will be considerably lower than that for Laxemar. From the safety perspective, therefore, Forsmark is clearly the most favorable site (SKB 2010:98).

In 2011, when SKB submitted its license application to construct a repository at Forsmark to the new regulator, the Radiation Safety Authority, SSM, the chart below, Figure 21, was included. That diagram clearly showed why the Forsmark site passed through the final Technical Suitability Filter.

It is instructive to contrast the Scandinavian experience with that of the effort to site a second repository in the United States. Implementers in all three countries faced a common task: narrow down the prospective settings, all in the same (crystalline) host rock, to potential sites and then to candidate sites. The Finnish and Swedish implementers looked first to the Host-Rock-Specific Criteria, groundwater flow and chemistry, affecting long-term safety. In Finland, those parameters did not distinguish among the four finalists, so other considerations brought the decision to closure. In Sweden, the projection of long-term safety for one of the sites was clearly superior to the other. The choice was

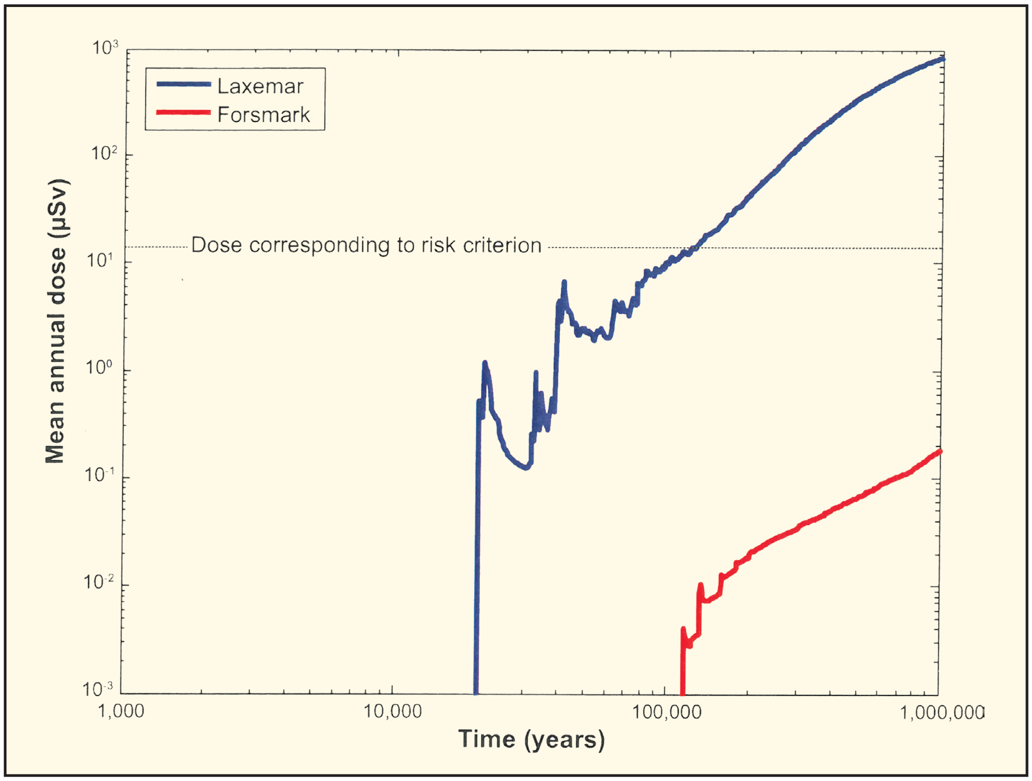


Figure 21. Results of safety analysis for candidate sites in Sweden (Source: SKB 2011a)

straightforward. And it was accepted without controversy, in part, because the comparative methodology simplified and clarified to interested and affected parties *why* the siting decision was made.

The experience with regard to the Second Round in the United States, however, was different. DOE's decision to use the site-suitability criteria based on Generic Criteria—the elaborate *Siting Guidelines*—to make comparisons among 235 prospective settings evoked a firestorm of controversy. The implementer found it extremely difficult to fashion a persuasive explanation of why it made the choices it did.

Generic Criteria (Multiple Disposal Concepts)

United States

It is unclear from the public record why DOE adopted such an elaborate approach to winnowing down prospective settings for the second repository, when, at essentially the same time, it embraced an uncomplicated and easily comprehensible approach, also based on that regulation, to narrow from nine to five to three the potentially acceptable sites for the first repository.

The *Siting Guidelines* lay out a six-step process for assessing the nine potentially acceptable sites and applying the Technical Suitability Filter:[120]

1. Sites that possess a disqualifying condition are eliminated.
2. The remaining sites are grouped according to their geohydrologic settings.
3. Sites within a single geohydrologic setting are compared.

[120] 10CFR960.3

4. Each preferred site within a single geohydrologic setting is evaluated to see whether it meets all the qualifying conditions.
5. Each preferred site within a single geohydrologic setting is appraised to determine if it is suitable for site characterization.
6. Sites within different geohydrologic settings are compared.

Steps 3 to 5, which are the functional equivalent of using Host-Rock-Specific Criteria as the basis for selecting sites, proved to be the decisive ones when DOE identified the five sites worthy of characterization.

Yucca Mountain and the Reference Repository Location at Hanford were in distinct geohydrologic settings: the Basin and Range and Columbia River Basalt regions, respectively. The seven other potentially acceptable sites fell into three geohydrologic settings: the Gulf Coastal Plain, the Paradox Basin, and the Permian Basin. (Recall Figure 6 on page 33 and Figure 13 on page 48.) In the first setting, Richton Dome was preferred over the Vacherie and Cyprus Creek Domes because it was larger, possessed no known dissolution features, experienced no known subsurface mining or mineral extraction, had limited potential for flooding, and benefited from few if any conflicts over land ownership. In the Paradox Basin, Davis Canyon was chosen over Lavender Canyon because the latter area was being considered for possible inclusion in the National Wilderness System. In the Permian Basin, the site in Deaf Smith County was selected over the Swisher County site because the former location had a downward groundwater gradient and was farther from populated areas. In this fashion, five sites emerged as contenders (Lomenick 1996:123-125).

The promulgation of the *Siting Guidelines* also seemingly set in place a framework for comparing three disposal concepts applied in five different geohydrologic areas. Appendix III of the regulation provides instructions on how system and technical guidelines are to be applied. But a clear articulation of a strategy disguised the difficulties in implementing it. As DOE discovered in the mid-1980s, the guidance proved to be minimally helpful.

These complications should not have caught DOE unawares. Several years earlier, the challenges of cataloging a set of Generic Criteria and gaining acceptance for a comparative methodology were noted in an NEA study.

> [Generic] criteria and statements of earth science data requirements are difficult to formulate because of the wide variations in host rocks available, their geologic setting, and the waste types to be accommodated. The lists of general criteria and data needs to encompass all situations will be long, and both the quantification and ranking of such criteria are dependent on geological factors, interrelated quantities, trade-offs, and the nature of engineered barriers to be used (NEA 1981:252).

DOE's first approach was to release in December 1984 *Draft Environmental Assessments* for each of the five candidate sites (DOE 1984d-h). Interested and affected parties submitted numerous written comments and presented oral statements at 19 public meetings in the six states hosting potentially acceptable sites. The input provided addressed:

- Policy and programmatic issues
- Siting processes and decisions
- Data and designs considered at each location

- Postclosure performance
- Preclosure radiological safety
- Environment, socioeconomics, and transportation
- Ease and cost of siting, construction, operation, and closure

For the purposes of this report, comments regarding the siting process and decisions are most relevant.

Many of the most critical observations were directed at the methodology for aggregating expectations about compliance with the pre- and postclosure system guidelines and with the 21 pre- and postclosure technical guidelines. As DOE observed: "The problem of selecting three of the five sites for recommendation reduces to aggregating the individual guideline-rankings. … Because the rankings differ … the overall rankings for all of the guidelines are not so readily apparent" (DOE 1984h:7-120). DOE proposed three alternatives for integrating the disparate rankings:

- Averaging: For each guideline group, the sites were ranked 1-5. The totals were weighted to reflect the unequal importance of each group. The weighted totals were then averaged.
- Pairwise comparison: All possible pairs of sites are compared. The number of times a site loses a pairwise comparison (i.e., is the less preferred of the two) is subtracted from the number of times it wins, to obtain a score for each site. Through a complicated and obscure algorithm, those scores are then weighted.
- Utility estimation: "The utility-estimation method is analogous to the judging and scoring of athletic competitions in diving and gymnastics, where the highest possible score is 10 and points are deducted for less-than-perfect performance" (DOE 1984h:7-120 – 7-124). The scores are then weighted.

The final rankings of the five potential sites differed depending on the aggregation method and on whether the sites were ordered based on preclosure, postclosure, or pre- and postclosure considerations. But according to the *Draft Environmental Assessments*, the sites in Deaf Smith County, at Hanford, and at Yucca Mountain were overall the most promising (DOE 1984h:7-131).

From the commenters' perspective, all of DOE's methodological alternatives were suspect. No sensitivity analyses were performed; the rankings were disconnected from the reported data; the aggregation procedures were invalid because some of the guidelines were redundant; the rankings failed to consider interactions among the major factors; and the weightings selected were never publicly reviewed (DOE 1986b:C.3-72 – C.3-74).

The volume and intensity of the methodological critique was reinforced by a letter from the National Research Council's Board on Radioactive Waste Management (BRWM).[121] The BRWM reviewed the key chapter in the draft assessments and concluded, "The methodology of comparative assessment is unsatisfactory, inadequate, undocumented, and biased and should be reconsidered …" (Parker 1985a). The first two alternatives were dismissed, almost out of hand. In the BRWM's view, if the third alternative, utility estimation, were

[121] The National Research Council is the operating arm of the NAS.

implemented rigorously, it might be used to supplement a more "scientifically defensible" method for rendering postclosure judgments: performance assessment.[122]

In response, DOE prepared a discussion paper describing a "more formal utility-estimation method … to provide a more defensible overall comparative evaluation of sites" (DOE 1985b). This 28-page document maintained that the performance assessments "that can be performed before site characterization are preliminary, inconclusive, and incomplete." At best, they could be used for "consistency checks" against a more formal methodology, multiattribute utility analysis (MUA), which DOE chose to adopt.

The BRWM reviewed this study. In an October 10, 1985, letter to DOE, it noted that the paper was a work-in-progress, lacking specific details about how an MUA methodology would be implemented. Nonetheless, the BRWM "commended" DOE for its adoption of MUA, calling it "an appropriate method by which to integrate technical, economic, environmental, socioeconomic, and health and safety issues." More importantly, it declared that "our concern about the appropriateness of the [DOE's earlier methodological choices] has now been addressed" (Parker 1985b).

A month after being provided a draft of the final Candidate Site Recommendation Report (CSRR), the BRWM again wrote DOE (Parker 1986). Three points raised in the letter are particularly noteworthy. First, the BRWM tacitly retreated from its position with regard to performance assessment, suggesting that it might be premature to use that technique until more data had been secured. Second, it clearly defined what role the MUA should play in the siting process. "The Board strongly supports the DOE position that the methodology is best applied only as a *decision-aiding tool* and that *additional factors and judgments are required* to make final decisions about what sites to characterize [emphasis added]" (Parker 1986:2).

Third, although the BRWM did emphasize that it had not reviewed the data and judgments on which the conclusions of the MUA would be based, it offered a strong endorsement of the approach.

> [W]e believe that the methods used in the CSRR provide a sound analytical basis for aiding the site-characterization decision. The Board commends the Department of Energy for taking the time and devoting the resources to identify and apply a comprehensive decision-aiding methodology. We believe that the methodology the Department has selected represents the "state-of-the-art" and is adequate and appropriate for this purpose. (Parker 1986:5)

DOE published the final version of the MUA in May 1986 (DOE 1986c). The analysis asserted that the sites were virtually indistinguishable in terms of their postclosure behavior. The projected releases from the three salt sites and Yucca Mountain were lower than the releases projected from the Hanford site, but the absolute differences were small and, in any case, were at least three orders of magnitude below the proposed EPA limit (DOE 1986c:5-15).

The MUA evaluated the sites against three preclosure outcomes: health and safety, environmental and socioeconomic impacts, and cost. In this evaluation, the differences

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122 A performance assessment uses complex models of the elements of a repository system to project how well the entire system will isolate and contain radioactive waste and what the human health consequences will be if the waste reaches the biosphere.

in the first two measures were overwhelmed by the difference in cost. Overall, Yucca Mountain ranked first, followed by the three salt sites, and then by the Hanford site (DOE 1986c:5-16).

The composite aggregation directly reflected the scores each site received on the pre- and postclosure performance components: Yucca Mountain was ranked first, Richton Dome placed second, and Deaf Smith was third. Lagging behind was Davis Canyon and Hanford.

Released along with the MUA was Secretary John Herrington's recommendation to designate three sites for in-depth characterization (DOE 1986d). On May 27, 1986, he advised President Ronald Reagan to select the sites at Yucca Mountain, in Deaf Smith County, and at Hanford. In explaining his decision, the Secretary made clear that the MUA was indeed "decision-aiding" not decision-controlling. His rationale for not simply accepting the composite results of the MUA—and, in particular, the choice of the Hanford site over Richton Dome—rested on three *policy* claims. First, even though the Hanford site scored the lowest in terms of its projected postclosure performance, that preliminary assessment still indicated that the site could comply with regulatory requirements with a significant margin of safety. Second, although the Hanford site scored lowest in terms of its projected preclosure performance, the ranking was strongly influenced by cost, a consideration, in DOE's view, that was secondary to other factors. Third, the NWPA calls upon DOE to the extent possible to "recommend sites in different geologic media."[123] Selecting a basalt site along with salt and volcanic tuff sites best satisfied this provision.[124] The day after receiving the Secretary's recommendation, President Reagan accepted it.

Each of the affected states marshaled technical arguments about why sites within it should not have been selected. The Yucca Mountain site was located in the vicinity of more than two dozen earthquake faults and might be disrupted in the future, as it had been in the past, by volcanic activity. The Deaf Smith County site lay above the Ogallala aquifer, one of the largest in the United States, which supplied freshwater to parts of eight states. The site at Hanford was riddled with fractures, which would make groundwater flow modeling very difficult and might also adversely affect the repository's constructability. Moreover, it was located near the Columbia River, which was already threatened by leaks of tanks holding HLW produced by the defense nuclear program. In the view of the State of Washington, a site in a salt dome differed as much from a site in a salt bed as did sites in basalt or volcanic tuff.

These technical claims would subsequently be debated not only in technical forums, but also in political and legal ones. This report considers how the site-selection process played out in all those venues when, in the next section, it discusses the Social Acceptability Filter used to restrict site characterization to Yucca Mountain in Nevada.

Exclusion Criteria (Single and Multiple Disposal Concepts)

France

In France, the 1991 Research in Radioactive Waste Management Act prescribed that candidate sites had to be investigated in both argillite and granite and that a comparison between two disposal concepts needed to be undertaken before reaching a final siting decision. The failure of the Granite Mission to find a volunteer community controlling a *specific* site that satisfied ANDRA's Exclusion Criteria placed the French implementer in somewhat of a

[123] NPWA Section 112(a).

[124] See also Lomenick 1996:Appendices I, J, and K.

quandary. It resolved this predicament in 2005 by studying generic architectural designs, based on the properties of the granite host rock and data gathered at URLs in Sweden and Switzerland (ANDRA 2005a). But, absent site-specific investigations, ANDRA could only conclude that a "repository in a granite formation is conceivable." The main uncertainty concerns "the existence of sites [in France] without a too high fracture density, which would be too demanding on repository performance" (ANDRA 2005a:151, 152).

Shortly thereafter, ANDRA also released *Dossier 2005 Argile*, in which it sought to demonstrate the feasibility of constructing a geological repository in an argillaceous formation (ANDRA 2005b). In making its case, ANDRA could rely on data gathered over six years at the URL near Bure that straddled the border between the Meuse and Haute-Marne *départements*.

For the French implementer, deciding on the feasibility of a possible repository meant that:

- There are technologies available to carry out all the repository phases.
- The technologies' implementation remains accessible (in particular, cost or development needs are not prohibitive).
- The selected geological medium has favorable characteristics to contribute to safe management.
- The technologies allow constructing, operating, closing, and letting the repository evolve under safe conditions over time scales varying up to several hundreds of thousands of years.
- The short- and long-term safety assessment of these concepts can be conducted with sufficient confidence.

Key, of course, was the development of the long-term safety case, consisting of a set of arguments about why the proponent believed that a deep-mined, geologic repository would satisfy regulatory requirements for performance. ANDRA's safety case was an intricately constructed argument that assessed the thermal, hydraulic, chemical, and mechanical evolution of the proposed facility over a period of several hundred thousand years and how the waste packages would respond to those changes. Once the packages degraded, radionuclides would enter into the host rock. They would travel slowly by diffusion, but the overwhelming fraction would be sorbed before leaving the argillite.

Some of the radionuclides, however, were predicted to escape into the biosphere. To ascertain the radionuclides' impact, ANDRA performed a series of safety analyses, which relied on the evaluation of several scenarios.

> The approach adopted to assess the repository impact therefore consists of representing the repository evolution in a simplified manner, referred to as a scenario. This scenario is not meant to provide an exhaustive description of the repository evolution. On the contrary, it offers a more readily understandable view, with phenomena represented so as to yield high or conservative repository impact values. All the phenomena present during the repository evolution are not necessarily represented, but this does not mean that they are neglected or ignored in the safety analysis. The results of the preparatory studies prior to the safety calculations determine whether phenomena are represented in a simplified manner or not at all. The scenario thus defined is therefore not an accurate representation of the repository evolution or a prediction of what will

happen. It is constructed so that the repository impact … will be *less* than the evaluated one in the scenario [emphasis added] (ANDRA 2005b:191).

To comply with French regulations, the implementer must show that the impact on an individual and the environment would be less than 0.25 milliSieverts for the first 10,000 years. According to ANDRA, international practice calls for calculations of dose to be carried out for as much as 1,000,000 years.

Based on its projections of the normal (most likely) scenario, the implementer claimed that only ^{129}I and ^{36}Cl would ever escape into the environment and only at levels four orders of magnitude lower than the regulatory threshold.[125] ANDRA also examined disruptive scenarios, such as human intrusion, nonperforming seals, and early container failure. It concluded that, even if multiple failures occurred—a very unrealistic event—repository safety "would still be maintained" (ANDRA 2005b:224).[126]

In 2006, an international peer review conducted by the NEA held that *Dossier 2005 Argile* "successfully establishes the feasibility of constructing a repository in the Callovo-Oxfordian (COX) argillites in the region of the Meuse/Haute-Marne URL" (NEA 2006:15). In particular, in the opinion of the peer reviewers, ANDRA implemented a safety evaluation method that was sound and appropriate and that there was great confidence in the key safety functions of the COX, that is, diffusion-controlled transport and radionuclide retention.

The discussion in this subdivision of this report suggests that passing potential sites through the final Technical Suitability Filter can be accomplished in more than one way.[127] Perhaps the simplest approach is comparing sites in similar hydrogeological environments on the basis of Host-Rock-Specific Criteria. The same disposal concept is deployed, and differences among potential sites are easier to explain and therefore easier to understand (and believe). In Sweden, two technical factors—groundwater flow and chemistry—distinguished Laxemar from Forsmark. In Finland, where evaluations of postclosure performance did not differentiate among the potential sites, several basic preclosure considerations convinced the implementer that the site in the Municipality of Eurajoki was more attractive than the other three candidates. In the United States, salt sites along the Gulf Coastal Plain and in the Paradox and Permian Basins were eliminated on the basis of elementary evaluations that evoked relatively little controversy. Based on these cases, it would appear that simplicity and analyzability may be as important as any other geologic characteristic in terms of passing a site through the final Technical Suitability Filter. This point is discussed in greater detail below.

It would appear that simplicity and analyzability may be as important as any other geologic characteristic in terms of passing a site through the Technical Suitability Filter.

More complicated was the situation in France. ANDRA arrived in Meuse/Haute-Marne because local communities invited it and because the area seemed to satisfy the implementer's Exclusion Criteria. Looking at one site that was compatible with only one disposal concept, ANDRA faced a stark "go-no go" decision. In response, it crafted a safety case

125 This result was largely unchanged in the sensitivity analyses that were conducted.

126 Strictly speaking, this passage through the Technical Suitability Filter and the French Parliament's ratification of that passage just meant that a "transposition zone" adjacent to Bure along the Meuse/Haute-Marne border was chosen. Efforts to select the precise location of the repository are still in progress.

127 It also can be done quite badly, as the experiences in central Kansas and Lower Saxony demonstrate.

that was straightforward, comprehensible, and readily testable. Over the years, using data obtained from a URL, ANDRA was able to advance arguments that, in a piece-by-piece fashion, allowed it to support a widely accepted claim of suitability.

By comparison, in the United States, the decision to winnow down five potential sites to three for the first repository and the screening to identify potential sites in crystalline rock for the second were enveloped by technical debates (as well as sharp political ones). In neither case could DOE's preferred outcome ultimately be sustained. The next subdivision of this section and the next section of this report, dealing with the Social Acceptability Filter, seek to explore some of the underlying reasons why.

Reflecting on Technical Suitability Filters in the United States

An examination of the historical record indicates that an implementer in the United States is confronted with exceptional constraints and demands, including geologic diversity and methodological complexity, both of which have to be addressed in a climate where technical arguments are often viewed through an interest-based lens.

The land mass of the United States is large and geologically heterogeneous. Figure 6 on page 33 shows how widespread salt deposits are. Analogous figures could be constructed for the two other leading host-rock formations, crystalline rock and clay/shale. In addition, more localized rock types, such as volcanic tuff and basalt flows, offer realistic technical possibilities for siting a repository.

By the late 1970s and early 1980s, the basic framework for disposal concepts in salt, granite, and several types of clay had been set in place. None of the disposal concepts, however, had yet been subjected to a strong empirical test. Consequently, the IRG argued:

> Further protection against debilitating technical risks could be obtained if a variety of geologic environments and emplacement media were examined in detail. Such redundancy in the examination of environments could be achieved sequentially or simultaneously (IRG 1978:42-43).

As this report notes above, Congress endorsed this policy by incorporating it as a requirement in the NWPA.[128]

That requirement directly prompted the development of the *Siting Guidelines*. Using its discretion, DOE employed these Generic Criteria in the Second Round to choose among sites in the *same* host rock. In its strict interpretation of the NWPA, DOE determined that the option of using Host-Rock-Specific Criteria, as the Scandinavians did, was foreclosed. DOE thus found itself having to assess 235 prospective settings by evaluating 25 requirements applied to 500,000 one-mile-square grids. It then had to aggregate the results using nine different weighting schemes. Under those circumstances, providing a simplified and clear

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[128] OTA 1985 makes the same point about technical risk. Of course, the technical community's collective understanding of different disposal concepts has grown over the past three decades. "Technical risk" is much less of a reason now than it was then for favoring geologic redundancy. Sites have been selected at which crystalline rock, clay/shale, and volcanic tuff disposal concepts might be implemented. But, as a recent DOE report clearly asserts, there is no technical basis for eliminating *a priori* any of these alternative approaches for developing a deep-mined, geologic repository (DOE 2014a). Thus, in the future, any implementer, just like DOE in the past, almost certainly will have to evaluate and compare sites found in different hydrogeological environments.

explanation to interested and affected parties about *why* decisions were made would inevitably require Herculean persuasiveness.[129]

> *Using Generic Criteria to choose among sites in the* ***same host rock*** *is unnecessarily complicated. Relying on Host-Rock-Specific Criteria is simpler and more transparent.*

As previous subdivisions of this report document, many of the provisions of the *Siting Guidelines* are obscure and open to conflicting interpretations. But more important, the regulation offers scant guidance on how to derive a single figure of merit that does justice to the various geological and operational criteria. If anything, this problem was even more acute when DOE had to judge sites in different hydrogeological environments. How does an implementer compare a salt site (and its associated disposal concept) with a granite site (and its associated disposal concept) when it is prohibited by regulation from giving much credit to engineered barriers?

Even theoretically, such a task may be so demanding that crafting a consensus approach is likely to encounter significant obstacles. For instance, the BRWM's initial preference for performance assessment when it first reviewed DOE's decision to winnow down five potential sites to three may not be an obvious solution. This method attracts its own set of criticisms. Moreover, using it when there is a paucity of data, as will typically be the case in the early stages of any site-selection process, only underscores its weaknesses.

> *Developing a technically sound methodology for comparing sites in* ***different host rocks*** *is challenging. Discretion will always have to be exercised to bring a decision to closure.*

DOE's technical challenges in explaining and justifying its choices were exacerbated because it operated in a politically charged and distrustful environment. Memories of the experience at Lyons had not faded 15 years later. The logic underlying the NWPA was that site selection would be driven by disinterested technical analyses and that comparisons would be made against clearly defined benchmarks. Warranted or not, ample evidence exists to support a claim that DOE was distrusted to discharge its legal responsibilities in a manner that was consistent with that logic.[130] Candidly put, concerns abounded that DOE would allow political imperatives to overwhelm technical ones. Perceptions about what motivated choices regarding the development of the *Siting Guidelines*, the cancellation of the second repository program, and the "decision-aiding" MUA did little to dispel those concerns. Consequently, the "reservoir of trust" needed for any agency to operate was largely absent. This report revisits this issue in the sections below.

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[129] Concerned about encouraging perceptions of bias, senior officials in OCRWM vetoed a plan to get a "reality check" on some of the potential sites, like the pluton under Lake Sebago in New Hampshire.

[130] See, for example, Carter 1987, a contemporaneous commentary, as well as later reports to two Secretaries of Energy, SEAB 1993 and SEAB 2000.

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 a direct function of 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 arise as a consequence of attitudes about things nuclear. Spenser Weart's volume, *Nuclear Fear*, captures well the origins of those beliefs (Weart 1988). And, 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 (see, for example, Slovic 1987). 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.

Special effects compound for implementers (and policymakers) the problem of siting a repository. Waste-management officials often lament that "if only" members of the general public "understood" the situation better, they would recognize that their fears were exaggerated and would offer less resistance.[131] This belief misconstrues the nature of risk percep-

[131] An unusually candid expression of this attitude comes from advisors to one state governor. "The predominant problem with spent fuel storage is one of public relations. One of the unintended consequences of the Nuclear Waste Policy Act is that it fomented the perception that nuclear waste, which by law must be permanently disposed of underground, is so dangerous and unmanageable that it must be buried underground or otherwise permanently removed from the human environment. Unfortunately a comprehensive, accessible public education/information campaign to effectively address these fears does not exist. Unchallenged and uncorrected, the public's misunderstanding of the risks and benefits of spent fuel will impede the country's ability to develop nuclear energy …" Letter from Governor's Nuclear Advisory Council (South Carolina) to Nuclear Regulatory Commission, November 22, 2013, p. 2.

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.

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 8. Standard and special effects

tions; nuclear fears appear to be well entrenched and relatively fixed. Further discussion of the difference between standard and special effects can be found in Box 8.

Moreover, although attitudes of the general public vary somewhat across countries, the differences are not substantial. A survey of residents of the 27 member states of the European Union, for example, found that 72 percent either totally agreed or tended to agree with the statement, "There is no safe way of getting rid of high-level radioactive waste." Only 14 percent disagreed or tended to disagree.[132] A breakdown of the aggregate results is particularly revealing: in Finland, France, and Sweden—countries that have the most advanced repository programs—82 percent of those surveyed concurred with the statement (EU 2008).[133]

Complicating the situation further, as this report observes above, is the matter of social trust. In this regard, substantial differences do obtain across nations. Both anecdotal and survey data suggest that the implementers in Sweden and Finland are considered by the general

[132] Lithuanians, Hungarians, Latvians, and the Dutch were more inclined to disagree or tend to disagree, although a majority in each of those countries did agree or tended to agree.

[133] No differences were found when the responses were analyzed based on age, education, or political philosophy. Only a small correlation was found with attitudes toward nuclear power.

public to be more trustworthy than their counterparts in the United Kingdom, Germany, and the United States. Importantly, social trust affects public attitudes toward siting a repository. Perhaps the most sophisticated analysis of this relationship was undertaken with respect to the proposed repository at Yucca Mountain. When an implementer of a national waste-management program sustains a high level of social trust, opposition toward siting a repository decreases (all other things being equal), *even if* a high level of perceived risk is present (Flynn et al. 1992). The converse also holds true. The relationship between trust and attitudes toward a proposed repository likely explains, at least in part, why the selection of sites in the Östhammar and Eurajoki municipalities evoked so little conflict, notwithstanding the very high level of perceived risk in both Scandinavian countries.[134]

It is in this context that Social Acceptability Filters emerge spontaneously or are deliberately constructed. And, just as Technical Suitability Filters evolve from being informal and heuristic to becoming more formal and systematic as the siting process unfolds, Social Acceptability Filters typically are either *ad hoc* or contingent at the earliest stages but become more well-defined and legalistic later on. As these Social Acceptability Filters take on more prominence, leaders of national waste-management programs increasingly assert that developing a repository is more of a social and political challenge than a technical one. Although those claims border on hyperbole, it is not hard to understand why they are being advanced.

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 evolve, immobilizing the siting effort, or organizing resistance based on either flawed technical arguments or deficiencies in the process.

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

Initially, implementers in most nations discounted the importance of the Social Acceptability Filter, believing that either governmental power or scientific authority (or both) was sufficient to enforce a siting choice. Certainly by the mid-1980s, those expectations proved unrealistic. With the exception of Finland, every country that has launched a siting effort has experienced a significant programmatic disruption 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 putative choice of Gorleben as a repository site paralyzed for several decades that country's efforts to dispose of its HLW and SNF.

Implementers did learn (but not always) from their experiences. One common response was to focus on locations where the influence of negative nuclear perceptions was low or

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[134] This inference is based on interviews as well as Sjöberg 2004 and 2006.

where the impact of positive standard effects was high. This strategy leads implementers to communities already hosting nuclear facilities and to economically underdeveloped areas. Thus, the Carlsbad community leaders approached DOE to construct WIPP because southeastern New Mexico 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.

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

The Finnish implementer was interested in the area around the Olkiluoto reactor from the start. Using the same logic, the Swedish implementer eyed the Östhammar and Oskarshamn municipalities. In the United States, the nuclear weapons complex sites in Washington State and Nevada were consciously thrown into the mix because public attitudes in the surrounding communities seemed favorable.

To understand in greater depth the critical role Social Acceptability Filters do in fact play, this report returns to the 24 historical cases worldwide that were analyzed in the section on the Technical Suitability Filter. In this section, this report also picks up the decisions in the United States to certify the WIPP repository and to focus site-characterization activities solely on Yucca Mountain.[135]

Deferral of Action and Reaction

In some of the cases involving preliminary screening of prospective settings and potential sites, neither the subordinate units of government nor interested and affected parties raised any strong objections and, in effect, choose to defer their response (either positive or negative) until the siting activity progressed. This occurred in the four cases listed below.

- Swiss Project Gewähr (1978-2004)
- Swiss Federal Office of Energy: Sectoral Plan (2008-present)
- Nuclear Waste Policy Act: Identification of nine potentially acceptable sites (1983)
- Nuclear Waste Policy Act: Identification of five sites for possible characterization (1984)

The explanations for why this approach was adopted are simple and straightforward.

Switzerland

In Switzerland, the objective of Project Gewähr was to identify potential sites for a repository constructed in crystalline rock. The effort was concentrated in the northern part of the country. A combination of two factors tempered public reaction. First, initial surface-based test results seriously called into question the suitability of that prospective setting. Second, Swiss law then provided for a binding cantonal referendum before a repository site could be selected.

The possibility of a cantonal veto was not merely a theoretical one. In 1993, the community of Wellenberg, located in the Canton of Nidwalden, emerged as the top candidate for

[135] Like the Technical Suitability Filters, siting efforts may have to pass through Social Acceptability Filters more than one time.

a long-lived, intermediate-level waste repository.[136] The leadership of both the community and the canton favored the construction of the facility, but, in a referendum, 51.9 percent of the voters rejected Nagra's construction application. Importantly, the technical suitability of the site was never strongly contested.

Over the next seven years, the federal and cantonal governments worked to modify the disposal concept and the process for implementing it. The federal government appointed an independent advisory committee, which recommended monitored long-term geological disposal and the continuation of work at Wellenberg (EKRA 2000). The canton established conditions for developing the repository and created its own advisory group to review the implementer's plans and oversee its activities. Believing that it had accommodated the concerns of the general public, the canton held a second referendum. The project was again defeated, this time with 57.7 percent of the vote.

The Wellenberg experience led the federal government in 2004 to revise the basic law governing the development of a deep-mined, geologic repository. A key provision of this legislation was the elimination of the cantonal veto; instead, the possibility of a national referendum, which dilutes the power of the canton, was put into place.

In 2008, the Federal Office of Energy launched the Sectoral Plan (SFOE 2008). The first stage was strictly a Technical Suitability Filter and was discussed in the previous section. It identified three potential siting regions for a HLW and SNF repository. The second stage, which began in January, 2012, was to select two regions and was scheduled to last two-and-a-half years. During this time, the siting regions would pass through a Social Acceptability Filter (as well as through additional technical ones). The process is illustrated in Figure 22 on page 94.

In April 2014, the Federal Office of Energy announced that Stage 2 of the Sectoral Plan would be extended for three to five years (SFOE 2014a). The reasons for the extension include prolonged participation, unrealistic schedules set at the beginning of the siting process, requirements from the cantons for additional technical investigations to make more informed comparisons of the regions, and regulatory requests for additional information.

By January 2015, the process had progressed to the point where Nagra was prepared to recommend two regions and three specific sites for the surface facilities. It eliminated the Jura-Südfuss, Nördlich Lägern, Südranden, and Wellenberg regions. Left in contention were the Jura Ost and Zürich Nordost regions. Further, Nagra recommended to the Swiss government that HLW and SNF be disposed of in a common repository along with long-lived low- and intermediate-level waste. Consultations continue with interested and affected parties (Nagra 2014; Nagra 2015). The outcomes of the down-selection process are shown in Figure 12 on page 41 and Figure 23 on page 95.

As Stage 2 proceeded, the question of cantonal versus national referendum arose again. Some interested and affected parties, recognizing that the possibility of a veto empowered the canton, began to lobby for a change in the 2004 nuclear waste law. Proposed legislation was approved in National Council, the house of Parliament elected based on population. Ironically, it was defeated in the Council of States, the house where cantons have equal representation.

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[136] For an overview of the Wellenberg controversy, see http://www.cowam.com/?Wellenberg.

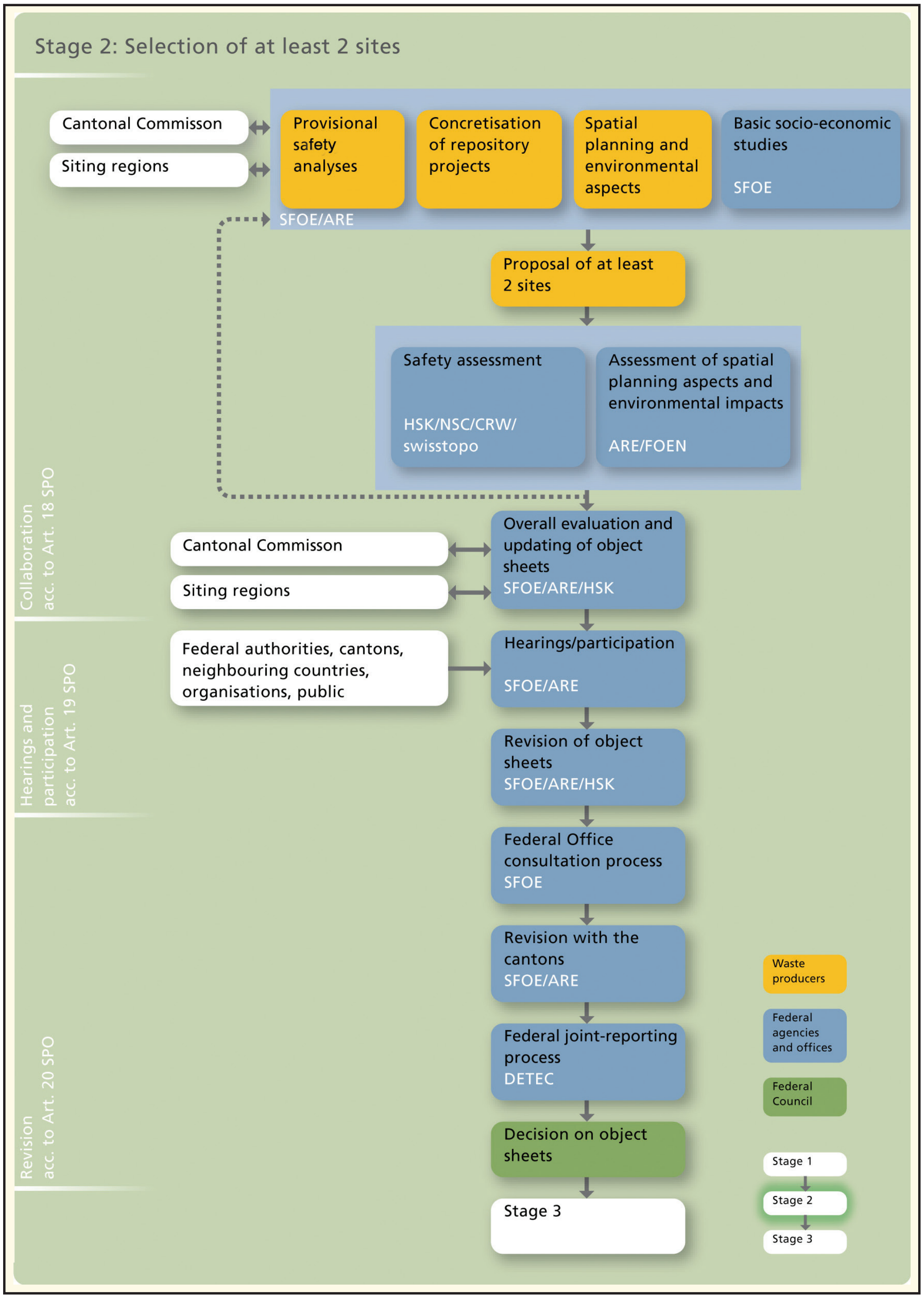

Figure 22. Stage 2 of the Sectoral Plan in Switzerland (Source: SFOE 2008)

Beyond this legislative activity, the cantons and interested and affected parties are letting the process play itself out, reserving the right to intervene more forcibly if future decisions warrant. One possible issue that might spark action by interested and affected parties relates to the scope of their involvement. Public discussions so far have been limited to exchanges about the location of the repository's surface facilities and not about the specifics of the postclosure safety case.

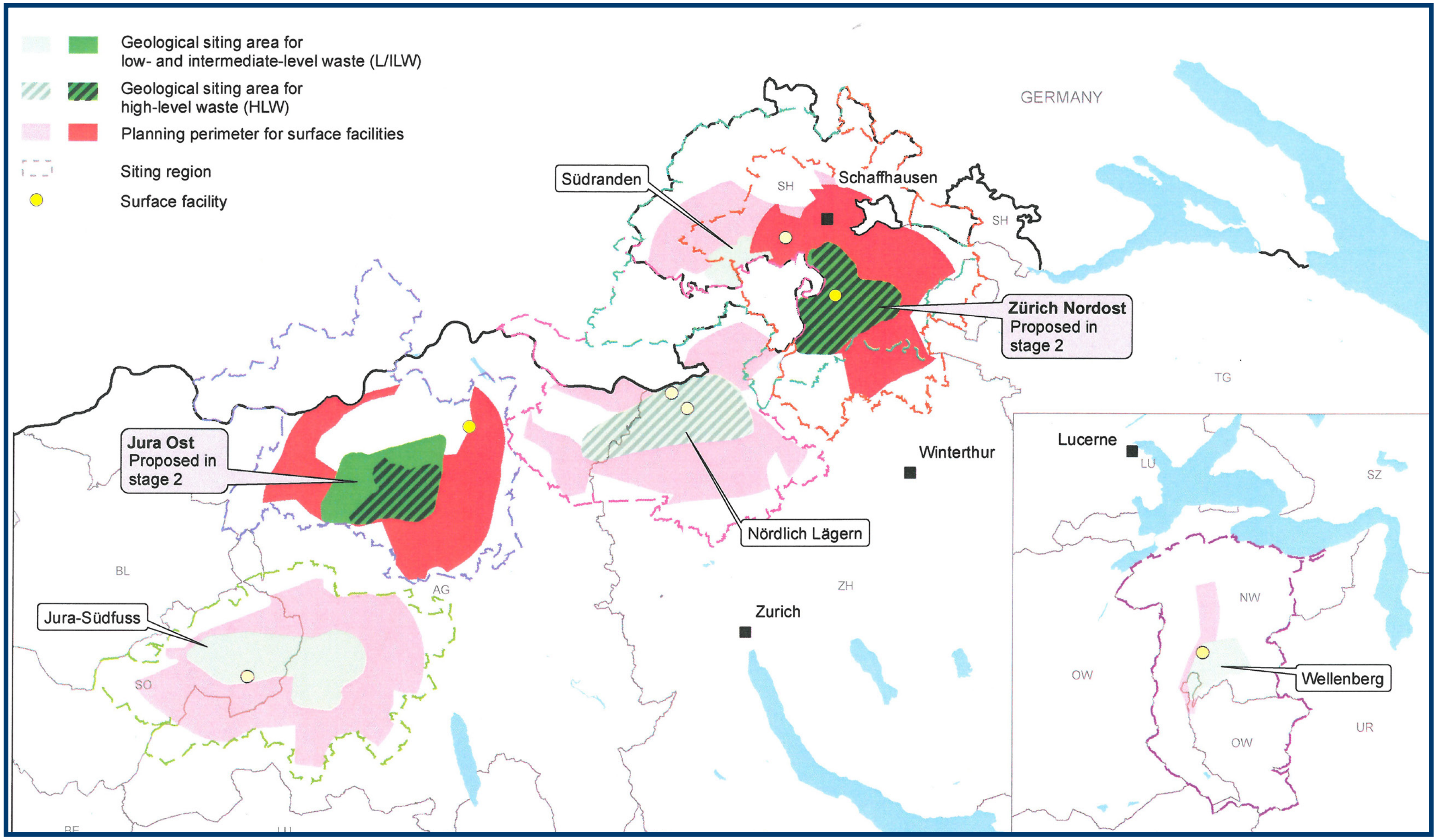

Figure 23. Nagra's proposed candidate sites for developing a repository for HLW/SNF and low- and intermediate-level radioactive waste (Source: SFOE 2014b)

United States

In the United States, the NWPA required DOE to identify potentially acceptable sites no later than April 1983. In discussions leading to the passage of that legislation, state officials confronted and largely accepted an elementary reality: given the milestones enacted in the law, only those prospective settings that DOE and its predecessor agencies had previously studied could reasonably be placed on the table. (This report discusses in the previous section and below how those locations entered into DOE's portfolio.) Moreover, DOE's technical evaluations had not advanced to the point that technical experts employed by the states could credibly critique them. Finally, many state officials were willing to defer their reactions to test DOE's commitment to conduct a fair site-selection process. In sum, DOE's choice of nine sites in six states evoked relatively little controversy.

In December 1984, when DOE in effect nominated five sites for possible characterization, the reaction from state officials again was subdued. This response appears largely to be attributable to the fact that the underlying political equation with regard to site selection did not significantly change. Duplicate sites in Texas, Utah, and Mississippi were eliminated, but a site in each of those states, along with the Nevada and Washington sites, was carried forward as a candidate for a repository. Only Louisiana fell out of contention.[137]

The quasi-passive stance illustrated by these four historical cases has, however, proven to be the exception not the rule.

Immobilizing the Siting Process

Nearly one-third of the historical attempts to site a deep-mined, geologic repository for HLW and SNF were prematurely and permanently terminated because the process was immobilized; the sites involved failed to pass through Social Acceptability Filters. These attempts were undertaken in the following cases:

- French Atomic Energy Commission (1987-1990)
- French Granite Mission (1999-2001)
- German Institute for Soil Research (1963-1967)
- German Nuclear Fuel Reprocessing Company (1973-1976)
- German AkEnd process (1999-2002)
- Swedish Nuclear Fuel and Waste Management Company (1977-1988)
- United States AEC, ERDA, and DOE (1972-1982)

In some of these instances, the so-called not-in-my-backyard (NIMBY) outlook provides a sufficient explanation for what transpired. In others, more nuanced motivations were at work.

France

By the mid-1970s, France had initiated an aggressive program to construct nuclear power plants. Between 1977 and 1989, 50 reactors, with a total capacity of 52,000 megawatt-electric, were put into service. At that time, public opinion about generating electricity from fission was strongly positive with 60 percent of the general public supporting continued

137 It is unclear how the political cards fell out in this case. On the one hand, a Louisiana senator, J. Bennett Johnston, chaired DOE's authorizing and appropriations committees. On the other, two influential Mississippi legislators, Congressman Trent Lott and Senator John Stennis, were on those same committees. The then-Vice President, George H. W. Bush, and the then-Speaker of the House, Jim Wright, were from Texas, and the then-House Majority Leader, Thomas Foley, was from Washington.

use nuclear power and only 14 percent supporting its termination. Attitudes about disposing nuclear waste, however, were markedly different.

In October 1987, even before ANDRA (then part of the CEA) scientists and technicians arrived on the scene, the mayors of the towns near the four potential sites (Deux-Sèvres, Maine-et-Loire, Aisne, and Ain) organized voter initiatives. Depending on the locality, between 75 and 95 percent of the voters expressed opposition to ANDRA's investigations (SKN 1992:43).[138]

At Deux-Sèvres, ANDRA was forced to use aerial surveys after ground survey lines were cut. At Maine-et-Loire, 400 armed police were called out to quell a demonstration. At Ain, opponents seized excavating equipment and burned documents after entering the local ANDRA office. In that community, special effects appear to have motivated the protesters. Bresse chickens and cheeses, produced in the area, are especially valued in France. Local farmers were concerned that a repository would stigmatize those agricultural products and reduce their value.[139] Outside of the targeted communities, a rally involving 15,000 people took place in Brittany, where several protestors were injured by the police.

By October 1989, the local and national protests had become so disruptive that the central government declared that the communities must cooperate with ANDRA and allow the implementer to conduct its site-investigation program. Otherwise, the government maintained, ANDRA would proceed under the protection of the police.

Such pronouncements were of little effect. If anything, they prompted the demonstrators to intensify their efforts. After beginning its investigations under police protection, ANDRA reconsidered its position and decided to stop drilling. And, on February 9, 1990, having just met with politicians and local opponents from Maine-et-Loire, Prime Minister Rocard announced a yearlong moratorium on the test drillings that were planned at the four potential sites.

As this report recounts above, the failure of ANDRA's first siting effort led to the passage of the 1991 Research in Radioactive Waste Management Act. That law resulted in the development of a URL in argillite near the community of Bure. (This story is discussed in detail below.) But needed still was a second URL that would be constructed in granite. To identify a volunteer locality sitting atop a suitable crystalline rock formation, the French government created the Granite Mission on August 3, 1999.[140] (See Box 7 on page 57.)

At the moment of its birth, however, the mission inherited conflicting and perhaps incompatible mandates. On the one hand, it was limited to considering only 15 areas, preselected on an "indisputable" technical basis. On the other, it was expected to engage in a "collegial consultation" exercise with the chosen communities. It did not take long for the contradictions in the mission's charges to manifest themselves.

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[138] It is unlikely that this resistance caught ANDRA by surprise. In late 1979 and early 1980, two efforts to develop waste-management facilities, one for HLW and the other for low-level waste, in the *Massif Central* aroused substantial public opposition and ultimately had to be halted.

[139] Initially, ANDRA referred to the site as the "Bresse" site but later changed it to the "Ain" site. In an attempt to increase standard benefits targeted to Ain, the national government granted manufacturers of Bresse cheese a special tax rebate (ERC 1989:II.3-10).

[140] What follows relies on Merceron 2000 and Mays 2004.

Barely two months after the mission's members were appointed, the Nuclear Phase-Out Network released the confidential map pinpointing the 15 localities.[141] The publication of the map had the immediate effect of undermining the mission's credibility with the communities' elected representatives and of galvanizing residents. A visit to the Corrèze *département* was met by 100 demonstrators whose shouting drowned out any attempt to communicate. A second outing to the Mayenne *département* was greeted by an "insulting and disruptive" crowd of 3,000 protesters. "When the members of the Mission finally reached the meeting hall, the chairman announced that the meeting was off, and the members were escorted to the borders of the *département* by protestors and farmers on tractors. … They were warned not to come back again" (Merceron 2000:128).

Over the next few months, demonstrations involving thousands of individuals were held in the Vienne, Côtes-d'Armor, Creuse, and Cantal *départements*. A coalition of opponents, the National Coordination against Burial of Radioactive Waste, along with the Green Party, organized meetings to protest the mission and its consultation efforts. Hundreds of mayors and leaders of General and Regional Councils signed petitions against the mission's work. Its members retreated to Paris and attempted to engage the localities via email and postal cards. But, faced with increasingly intense resistance, the French government terminated the mission. The group's dissolution was so precipitous that, just three months earlier, ANDRA's Chairman had predicted a successful outcome of its work (Le Bars 2000).

In this case, both standard and special effects played a part in arousing opposition to the siting of a URL. Many of the targeted areas had adopted a development strategy of relying on "green tourism," which would have been compromised by the presence of a nuclear facility. Approximately 20,000 seasonal jobs in each *département* would have been at stake. At the same time, "it was feared that the URL and possible repository would alter regional identity and image, tainting them with radiation stigma, and thus pose a direct threat to economic health" (Mays 2004:30).

In its final report to the French government, the mission's members strongly criticized the total absence of countervailing views and held that the silence of national partners had significantly destabilized the country's waste-management program. It noted that "legislators, institutions, administrations, research organizations, major [industrial] actors, and scientists [did not] take the floor to deny or correct [opponents'] declarations, to complement or to illuminate the discussion" (Granite Mission 2000:41). As one analyst notes: "The absence of discourse explaining and supporting the program was a disservice to citizens. The members of the public who did come to dialogue during the local visits … bear witness, according to the Mission, to the public's 'great need for knowledge and understanding' of high-level radioactive waste, its risks, and its management in France" (Mays 2004:31).

Germany

In Germany, potential repository sites were identified in the mid-1960s by the Institute for Soil Research. The historical record, at least in English, explaining why those siting efforts failed to pass through the Social Acceptability Filter is virtually nonexistent.[142] One source

[141] The map was apparently leaked by political appointees in the Environment Ministry, whose chief was a leader of the Green Party.

[142] BMWi 2008 is the only source that refers to the earlier siting attempt. The standard references, ERC 1989, Carter 1987, Emel et al. 1990, Blowers et al. 1991, Kemp 1992, Hocke and Renn 2009, and Streffer et al. 2011 do not mention it.

refers somewhat cryptically to "problems purchasing sites" as well as generalized public opposition to the siting activities in the 1960s.

The historical record concerning the efforts undertaken in the early 1970s by the German reprocessing company, KEWA, only recently has become more complete (Tiggemann 2010). As this report discusses in the previous section, the firm was primarily interested in finding a site that would accommodate a reprocessing plant. A salt dome would be needed to dispose of the liquid low- and intermediate-level waste from that facility. An added bonus would be finding a salt formation nearby that could be used to dispose of solidified HLW as well.

KEWA concentrated its site investigations at Wahn. (See Figure 7 on page 35.) Residents of the area objected, complaining that they were never notified about the company's interest. They were supported by members of the Federal and *Land* legislatures, who were members of the Christian Democratic Union. Large protests were mounted near the Dutch border. Drilling stopped at Wahn, and KEWA turned to its lower-ranked potential sites: Lutterloh and Lichtenhorst. There, too, objections and protests arose. In the area around the former site, activists formed the Environmental Protection Green Slate, a precursor to Germany's Green Party. In addition, the Lower Saxony Ministry of Agriculture complained about possible impacts on the water supply and land stewardship. It was at this point that the Lower Saxony Minister of Economy stepped in. He and the Federal Minister for Research and Technology agreed in August 1976 that all drilling should stop and that future siting efforts should be led by state officials. Gorleben emerged as their choice.

As this report also describes in the previous section, from the late 1970s onward, the presumptive repository site near Gorleben dominated discussions of where Germany should dispose of its HLW and SNF.[143] In 1998, however, a coalition of the Social Democratic and Green parties gained a majority in the Bundestag, one house of the Federal Parliament. Among other issues, including the role of nuclear energy in Germany's future, the pre-election agreement cementing the parties' relationship expressed doubts about the suitability of the Gorleben site and called for a reconstruction of Germany's radioactive waste-management policy. That political commitment led directly to the formation of the Committee on a Site Selection Procedure for Disposal Sites, AkEnd, and its three-year-long public process.[144]

The German government imposed four constraints on the committee's deliberations:

- It had to start with a blank "white map" of Germany.[145]
- The only long-term management option that could be considered was disposal in a deep-mined, geologic repository.
- Only one repository could be constructed, and it would have to accept all forms of radioactive waste.
- The operation of the repository would have to begin no later than 2030.

The 14-member committee included geoscientists, chemists, physicists, engineers, social scientists, and communications specialists. Proponents and opponents of nuclear power were represented. Technical and engagement working groups supported the committee's

143 The application of the Social Acceptability Filter in the case of Gorleben is discussed below.

144 The BMU was responsible for the appointment of the AkEnd committee. Its Minister, Jürgen Trittin, was a member of the Green Party.

145 This was another way of instructing the committee to ignore the two investigated sites, Gorleben for HLW and SNF and Konrad for low-level waste.

work. It held three public workshops, convened 27 public meetings, sponsored 67 working group sessions, and participated in 15 rounds of talks with members of the Federal and *Länder* parliaments and other interested and affected parties. Notwithstanding this activity, the committee's activities never received much coverage in the media.

In its final report (AkEnd 2002), the committee proposed an elaborate set of qualifying and disqualifying conditions that would be used to winnow down prospective settings to potential sites and, after underground exploration of at least two of those sites, to make a final selection of one for development as a repository. The committee recommended that interested and affected parties should review and discuss the specific Generic Criteria and the proposed process for down-selecting sites.

At this point, the Social Acceptability Filter was applied. The Ministry of Environment, Nature Conservation, and Nuclear Safety (BMU), which impaneled the committee, attempted to organize a "negotiation group" to consider the AkEnd proposals. It never got off the ground. Part of the difficulty can be traced to the inescapable shadow cast by the Gorleben site. From the perspective of the opposition political parties, the Christian Democratic Union, its Bavarian ally, the Christian Social Union, and the nuclear industry, Gorleben was a suitable site. Moreover, the industry had paid to characterize it and was not inclined to pay a second time. Lower Saxony, now governed by opponents of the Bundestag majority, made continuation of investigations at Gorleben a precondition for its participation (Appel 2006).

Other forces contributed to AkEnd's demise. None of the *Länder* looked favorably on the prospect of reopening a site-selection process. Other affected Federal ministries were suspicious of BMU's motives and were reluctant to join into deliberations that might bind them to policies they could not fully support. One influential segment of the technical community, an international expert group that advised the *Länder* of Bavaria, Baden-Württemberg, and Hesse on nuclear matters, panned the committee's recommendations. In addition to attacking the constraints that the government had imposed, including the requirement for a single repository and the refusal to consider Gorleben, the group criticized the committee's proposed Exclusion Criteria as being too restrictive and dismissed the committee's ideas about public participation as being too cumbersome (ILK 2003).

Faced with this intense opposition, the BMU Minister, Jürgen Trittin, withdrew his support of the AkEnd process in the fall of 2003. As an alternative, his Ministry prepared draft legislation in 2004. A key element of the proposed law was the transfer of implementation responsibility from the Federal Government to an association of nuclear utilities. Envisioned was a new organization modeled along the lines of SKB and Posiva Oy. This bid became moot when the results of the 2005 Federal election brought to power a "grand coalition" comprising the Christian Democratic and Social Democratic parties. The two partners, however, could not agree on nuclear energy policy in general and waste-management policy in particular. What followed was nearly a decade in which radioactive waste management suffered from not-so-benign neglect.

The 2011 decision to phase out nuclear power in Germany may have created the necessary conditions for progress to be made in developing a common approach to siting a disposal facility. As this report discusses above, the Repository Site Selection Act passed in 2013 effectively sets Gorleben aside, at least for the moment; it recognizes that disposal concepts other than salt might be possible and it creates a new institutional framework for recommending a process for developing a deep-mined, geologic repository for HLW and SNF. Importantly, this legislation emerged out of discussions that included the *Länder* and all the major political parties. But the ultimate fate of this initiative still hangs in the balance.

Sweden

In Sweden, the implementer's decision about *where to site* a repository is not subject to formal approval by governments at either the national or local level, unlike the granting of a license to *construct* a repository. Perhaps it was this apparent disconnect that explains what transpired in the late 1970s.

In its report on the Swedish siting process, SKB makes scant mention of the early investigations that many believed were designed to identify prospective settings for a possible deep-mined, geologic repository for HLW and SNF. (See Figure 8 on page 37.) SKB notes that 85 cored boreholes were drilled with a combined length of 45 kilometers. Special care was taken to determine the permeability of the rock and the chemical composition of the groundwater at great depth, the two Host-Rock-Specific Criteria associated with the KBS-3 disposal concept. "The results of the study site investigations showed that it is possible that many places in Sweden are suitable for building a repository" (SKB 2011a:17). What the report fails to mention is how this early siting experience influenced the construction and application of the Social Acceptability Filter later on.[146]

The first test drilling was carried out in 1977 at Finnsjön, close to the Forsmark nuclear site. Explorations at Kråkemåla, near the Oskarshamn nuclear site, and at Sternö followed. These activities attracted little public attention.

When the studies were expanded in 1980 to Kynnefjäll on the west coast, however, the community's reaction was especially strong and negative. Building on their previous resistance to siting first a reprocessing plant and then a four-reactor complex, local citizens reconstituted a group, Rädda ("Save") Kynnefjäll, with the avowed purpose to prevent the test drillings.[147] The group erected a guard hut on a hillside overlooking the sole road leading to the site where the testing would be carried out (Figure 24). The vigil lasted 20 years, until 2000, when SKB signed an agreement with the municipality that it would not dispose of SNF in Kynnefjäll.

Figure 24. Guard hut in Kynnefjäll (Source: KynnefjällsNatur)

Resistance movements also grew up in Svartboberget in 1981, in Klipperås in 1983-1984, and in Almunge in 1985-1986. Although shorter in duration than the one in Kynnefjäll, these protests were at least equally intensive. "Arrests, court appearances, and fines followed. The national media gave

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[146] Below, this report describes how subsequent siting activities passed through Social Acceptability Filters.

[147] See Lidskog and Elander 1992 for the most complete discussion and interpretation of the demonstration in Kynnefjäll. Although SKB received permission to conduct studies from the owner of the lands in question—the government-owned Swedish Forest Service—and the government was prepared to fund the investigation, it is unclear from the available historical record whether the drillings ever took place.

[the protests] extensive coverage, and SKB was reprimanded by the Minister of Energy and the Environment in the Almunge case for creating a confrontation and not properly informing the community in advance of its plans" (Blowers et al. 1991:280).

The public demonstrations in these municipalities were complemented by threats to invoke the provisions of the Act Concerning the Management of Natural Resources that, during this period, granted municipalities an unconditional veto over activities they felt were incompatible with local development plans and regulations. Those pressures helped to accelerate the debate whether to amend the law to condition a municipality's veto rights.[148]

In 1990, the law was, in fact, changed so that the central government could override a local veto over the licensing of a repository, but only if:

- It is important that the facility be established, from a national perspective.
- No other municipality with a suitable site is prepared to accept the facility.
- No other site is considered to be more suitable.

Notwithstanding the possibility of overriding a veto, more theoretical than tangible because of the stringency of the conditions and a political culture highly valuing local control, SKB's long-standing view is that it would not site a repository in the face of local opposition.

United States

The same pattern of political opposition that arose in France, Germany, and Sweden repeated itself in the United States as ERDA in the mid-1970s and as DOE later on tried to resuscitate an HLW and SNF management program battered by the experience in Kansas and the rapid end of the RSSF initiative.[149]

The Salina Basin, which covers most of Michigan and extends through northern Ohio into western Pennsylvania and New York, contains a bedded-salt formation that meets well the Host-Rock-Specific Criteria for selecting a potential salt site. (See Figure 6 on page 33.) In late 1976, ERDA started to support investigations by ORNL scientists in the Lower Peninsula of Michigan, near the town of Alpena. Concerned that ERDA might be targeting the region, the governor and the congressman who represented the Alpena area mobilized opposition. Because the state had to issue permits before boreholes could be drilled, it held a powerful card *vis à vis* the federal agency. A House of Representatives committee conducted contentious hearings, and Governor William Milliken made it clear that he would not negotiate, not discuss the matter with ERDA, and certainly not allow drilling until he received an unambiguous, written pledge that Michigan would not be selected as a repository site without the state's approval.

ERDA oscillated on whether to accede to the governor's demand. At first it argued that developing a repository was a federal function that was not subject to a state veto; then it decided that it would not site a facility over objections, raised presumably by state officials; then it reserved to the right proceed; and finally ERDA proffered an ambiguous commitment to terminate siting activities if the state raised unresolvable issues. Reflecting on this back-and-forth, the governor concluded that all investigations should come to a halt

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[148] The municipalities dealing with SKB were not pleased. As one leader of the Kynnefjäll protest remarked, "If the municipal veto is taken away, you will not only have civil disobedience but also municipal disobedience!" (quoted in Lidskog and Elander 1992:258). For an excellent discussion of the evolution and interpretation of the municipal veto, see Swedish National Council 2014a:85-100.

[149] The discussion that follows draws on Lomenick 1996:29-44 and Carter 1987:145-193.

even before any ground was turned. Aside from being skeptical of ERDA's intentions, he was concerned about the strong likelihood that a repository located near the Great Lakes would bring with it major negative economic impacts.[150] The following year, Michigan passed a law forbidding the disposal of radioactive waste within its boundaries.

Much the same sequence of events played out elsewhere in the Salina Basin. Even the slightest possibility that an area near Cleveland might be suitable for a repository catalyzed Ohio's Governor James Rhodes, who was in the midst of a tight reelection battle in 1978. Nor was the possibility of federal help in cleaning up Nuclear Fuel Service's shuttered reprocessing plant in West Valley sufficient to gain the support of New York's Governor Hugh Carey. That ERDA had identified prospective settings in the Finger Lake district, a vacation spot where many wineries operated, did little to make site investigations more palatable.

A preliminary study carried out by the new Battelle Memorial Institute-run Office of Nuclear Waste Isolation pinpointed the Gibson Dome in Utah's Paradox Basin as a prospective setting. Situated in economically struggling San Juan County, the local population appeared to be open to a major infrastructure project that could mean new jobs. As it turned out, however, DOE was interested in two potential sites, Davis and Lavender Canyons, both of which were adjacent to Canyonlands National Park and the Colorado River. Governor Scott Matheson, who might have been open to repository development elsewhere in the state, had no choice but to oppose vigorously DOE's plans. He was joined by national and regional environmental action and conservation groups. In 1982, the governor imposed a moratorium on state cooperation with DOE and denied it right-of-way across state lands.

ERDA's siting work in the Palo Duro subbasin of the Permian Basin in the Texas Panhandle got off to a promising start. Not only did patriotic sentiments facilitate the agency's task, but the weak state of the local economy heightened the value of potential new jobs. As the publisher of the leading paper in the area put it, "Farming's been kinda slow, and there's not much money circulating. Of course, a lot of people are still afraid. Most are taking a wait-and-see attitude."[151]

It was, however, the specific location of the prospective settings in Deaf Smith and Swisher counties that complicated and obstructed DOE's relationship with the local community. Both sites lay under the Ogallala aquifer, which provides water to people and farms stretching from New Mexico to Nebraska. Although any repository would be constructed 700 meters below the aquifer and would be separated from it by nearly 350 meters of salt, shafts through the water body, if compromised, could carry offsite the waste to be emplaced in the facility.

Even though DOE's siting work evoked little public protest initially, the calm did not last long. Opposition groups formed in both counties. Representatives of agricultural associations and the Catholic Diocese of Amarillo, more than 50 miles away, testified at public hearings organized by DOE. Governor Bill Clements preferred to work behind the scenes to block the selection of either location, but the state's Commissioner of Agriculture, Jim Hightower, launched a very visible campaign, maintaining that land beneath a major freshwater aquifer "could never be a suitable site for a repository" (quoted in Carter 1987:156). The Frito-Lay Corporation complained that "it does not take much imagination to conjure

[150] Letter from Governor William G. Milliken to Robert Fri, Acting ERDA Administrator, May 11, 1977.
[151] Quoted in Jere Longman, "Tulia Losing Fear of Nuclear Waste," *Dallas Times Herald*, January 21, 1982.

up the hue and cry of the public about food crops being irrigated by water that flows over nuclear waste."[152] Directly linked to this resistance was the enactment of legislation in 1983 forcing anyone who wished to drill through the Ogallala aquifer to obtain a permit from the Texas Water Commission.

Along the Gulf Coastal Plain, DOE's position in Mississippi also soured quickly. State officials at first accepted the Federal Government's authority to conduct site investigations. But learning from the experience of their brethren in the Midwest, the Mid-Atlantic, and Western regions, Mississippi soon asserted its state's rights. The opposition was encouraged because DOE was focusing on two potential sites that had troubling attributes. The first, Richton Dome, was located just outside its eponymous town. The second, Cypress Creek Dome, showed signs of salt dissolution. Accordingly, in 1981, Governor William Winter sought and received from DOE a moratorium on further field studies. The legislature passed an act that established a labyrinth of conditions before any future fieldwork for a repository might be carried out.

DOE believed that the Vacherie Dome in Louisiana was a potentially suitable site for a repository. A cooperative arrangement with scientists at Louisiana State University appeared to be a valuable vehicle for drilling the first test boreholes in 1977. Two local citizens, however, had other ideas, and they organized a group that caught the attention of state officials. In bargaining with DOE to develop the Strategic Petroleum Reserve in a salt dome, Governor Edwin Edwards received a commitment in 1978 that no waste would be disposed of in Louisiana without the state's consent. During the presidential race in 1980, his successor, David Treen, convinced soon-to-be-President Reagan to honor that promise.

In sharp contrast, the Reference Repository Location, within the thick Columbia Plateau Basalt Group that underlies the Hanford Reservation, was touted as the ideal location for a disposal facility by the citizens in the Tri-Cities region of Washington State. Given the pivotal role that Hanford plays in the area's economy, state officials were not inclined to take on directly DOE's siting activities. But they were well aware of the strong anti-repository attitudes that were held by the public outside the region: a 1980 ballot initiative to prohibit disposal in Washington of most nuclear waste from outside the state was endorsed by a substantial majority of voters.

State leaders concluded that their best strategy was to seek the technical advice of scientists and engineers who were independent of DOE. Although their counsel was not unanimous, most agreed that digging access shafts five meters in diameter would represent a formidable engineering challenge; that groundwater travel times would be relatively rapid; and that flooding would pose a continual risk to the mining of the repository itself. With this information in hand, officials felt confident that they had a strong technical case for preventing the development of a repository at the site.

If Hanford was technically problematic, disposing of HLW and SNF in the volcanic tuff at Yucca Mountain on the arid Nevada Test Site seemed to be technically elegant. When investigations started in 1979, the focus was constructing a facility in the saturated zone. The poor mechanical strength and low thermal conductivity of the Bull Frog and Tram tuff layers caused DOE in 1982 to shift its attention to the unsaturated zone. It would subsequently

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152 Letter from Charles Murphy, Vice President for Government and Consumer Affairs, to Congressman Ken Hance, cited in Carter 1987:157.

develop a safety argument founded on the presumption that whatever water traveled beyond the surface would move extremely slowly down to the repository and onward.[153]

Although there is no question today about Nevada's position regarding the proposed Yucca Mountain repository, arguments continue about when state officials first came to oppose it. The aboveground nuclear weapons tests dating back to the 1940s undeniably left a permanent mark on the public's psyche as well as produced tangible health effects on the "downwinders." That checkered history clearly contributed to a lack of trust in DOE. Concerns about whether a transportation accident in the vicinity of Las Vegas might stigmatize that gaming destination were raised early on. In 1979, an anti-nuclear group began campaigning against a possible repository. Certainly, if in the early 1980s the state was willing to give DOE the benefit of the doubt, with the passage of the 1987 Nuclear Waste Policy Amendments Act, Nevada had become implacably opposed to Congress' and DOE's siting plans.

Resistance Driven (at Least in Part) by Compromised Technical Arguments

If, as this report maintains, technical suitability is the *sine qua non* for the choice of any repository site, it is hardly a revelation that challenges to selecting a location for that facility can arise if the technical claims about the safety case are called seriously into question. That statement should not be interpreted to mean that the overriding objective of opponents is necessarily the enshrinement of scientific and engineering "truth." Clearly, there may be multiple bases for resistance, such as opposition to the use of nuclear power or concerns about due process. But it is equally clear that weak technical arguments make it harder to pass a site through the Social Acceptability Filter. One historical case provides an example of this: the decision by the AEC to choose Lyons, Kansas, as the site for a demonstration repository (1971-1972).

United States

Within 15 months from when the AEC issued a draft EIS in November 1970, the selection of the Lyons location failed to pass through the Social Acceptability Filter.[154] The rapid collapse of the siting process was due in large part to lobbying by the Director of the KGS, William Hambleton, and Representative Joe Skubitz, even though his district was two counties away from the Lyons site. Governor Robert Docking and Senator Robert Dole played subsidiary, but crucial, roles.

From Hambleton's perspective, the issue of whether bedded salt was a suitable disposal host rock was separate from the issue of whether the Carey Mine was a suitable site. However, because he had just co-authored the NAS report that gave a tentative endorsement to the AEC's decision (NAS 1970), he needed to articulate a sound technical basis for clearly distinguishing the two questions.[155]

With support from the AEC, the KGS prepared a report evaluating the suitability of the Lyons site. A December 1970 preliminary study criticized the AEC and ORNL models

[153] The technical argument for developing a repository in the unsaturated zone was first made in Winograd, 1974. This report describes above the fundamental reconceptualization of the original safety argument.

[154] This description draws heavily on De la Bruhèze 1992.

[155] Recall that the NAS report called for additional site investigations, which in the report authors' view, would not turn up any surprisingly negative information.

used to assess heat flow, heat dissipation, radiological damage, and surface subsidence and pointed out the presence of potentially disruptive shale layers in the salt formation (KGS 1970). A final report reiterating those concerns appeared two months later. The KGS's technical assessments informed the state's comments on the draft EIS. As important, they elevated the siting decision for Kansas' political leadership.

Congressman Skubitz was the most active in voicing his opposition. His initial objection centered on how the AEC treated outsiders. In a letter to AEC Chairman Glenn Seaborg, Skubitz proclaimed:

> While I am not surprised with the bureaucratic doubletalk, the Orwellian jargon that war is peace, I am chagrined and disappointed with your own letter. If this is the kind of answer that a member of Congress seeking specific and unambiguous answers to his questions receives, it is obvious why the AEC depository [sic] plan has become suspect and why Kansas citizens must become increasingly wary of AEC machinations.[156]

Skubitz then convinced Governor Docking that the safety of the project had to be demonstrated *before* state officials could sanction it.

In turn, Docking persuaded Senator Dole to introduce an amendment to the AEC Authorization Act of 1972. The change would prevent the AEC from purchasing the site for at least three years and would require that the burial of wastes be postponed until the complete safety of the repository could be certified by an independent advisory council appointed by the President. The amendment passed in August 1971.

As these events were unfolding, information began to trickle in about the oil and gas boreholes that could not be plugged, the solution mining, and 175,000 missing gallons of water. This evidence reinforced concerns raised by EPA and the Department of the Interior about the dearth of data related to the long-term safety of the proposed repository. The unified Kansas delegation soon found other supporters in Congress. Even the Chairman of the powerful Joint Committee on Atomic Energy, Senator John Pastore, cautioned Seaborg: "A governor is a pretty important person in his state. He is the Number One citizen. I don't think you should run roughshod over him, and nobody wants to do that."[157]

Although a core of supporters at the AEC held out the hope that the Lyons site could be made suitable, the handwriting was on the wall. In September 1971, the project was suspended. Five months later, the AEC withdrew its request for funding to construct the demonstration repository.

Resistance Driven (at Least in Part) by Concerns About Process

In Germany and the United States, resistance to siting choices was also motivated by a belief among many interested and affected parties that the process employed was biased and tainted. Three of the historical cases involve Social Acceptability Filters that manifested this type of concern. They resulted in contrasting outcomes, at least in the near term.

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[156] Letter from Representative Joe Skubitz to Glenn Seaborg, AEC Chairman, March 1, 1971.

[157] *Hearings before the Joint Committee on Atomic Energy on AEC Authorizing Legislation for Fiscal Year 1972*, 92nd Congress, 1st Session, Part 3, March 1971, 1445.

- The decision by the Government of Lower Saxony to select Gorleben (1976-present)
- DOE's site selection for the second repository (1983-1986)
- DOE's nomination of three sites for characterization for the first repository (1985-1987)

Germany

If the dispute over the site in Kansas can best be described as acute, then the dispute over the Gorleben site in Germany can best be described as chronic. Recently released documents from Lower Saxony's state archives allow a much more complete story to be told (Tiggemann 2010).[158]

Even before the government of Lower Saxony took control over the siting process in the August 1976, it had informed KEWA that it should consider 20 additional sites. In doing so, the *Land* shifted the siting strategy. Instead of looking first for areas where a reprocessing facility could be constructed and *then* investigating whether suitable salt domes could be found nearby, the new approach was first to identify potentially suitable repository sites and *then* to look at land around them to find an area where the plant could be constructed. Gorleben was included among those 20 supplemental locations. KEWA then employed the same methodology to evaluate eight of the 20 sites and to compare them with Wahn, Lutterloh, and Lichtenhorst. Gorleben emerged from this Technical Suitability Filter with the highest rank. (See Figure 7 on page 35.)

In November 1976, President Albrecht, a member of the Christian Democratic Union, met with Federal ministers from the ruling Social Democratic/Free Democratic governing coalition. At that meeting, one of Albrecht's aides mentioned that Gorleben was emerging as the preferred site. The ministers raised concerns that Gorleben lay just across the Elbe River from the German Democratic Republic (East Germany). In case of tensions, the communist nation might attack the repository or tunnel beneath the river and damage the salt dome. Those misgivings were weighed against the belief that the local population would likely support the development of a repository. In the end, Gorleben's proximity to the border was not viewed as a fatal flaw.

At a meeting of the Lower Saxony cabinet in December 1976, the technical, environmental, and socioeconomic pros and cons of a number of sites were discussed. Gorleben, Lichtenhorst, Wahn, and a new contender, Mariaglück, came out on top. Two weeks later, a cabinet vote made it official. Federal Chancellor Helmut Schmidt, a Social Democrat, asked Albrecht to withdraw the proposal for Gorleben or at least to name an additional candidate site. Albrecht declined. Nonetheless, in February 1977, the Federal authorities accepted Lower Saxony's designation of the site.

After consultation with the other parties represented in the Lower Saxony Parliament, Albrecht wrote letters to the presidents of nearby *Länder*. In that correspondence, he indicated that his decision was based on three factors: technical suitability, absence of organized opposition, and the need to provide an economic stimulus to the area.

Just as Gorleben has been stuck in the Technical Suitability Filter for more than two decades, so too has it been trapped in the Social Acceptability Filter for at least as much time. Gorleben's fate has become inextricably linked to the larger question of what role

[158] The events surrounding the selection of potential sites in Lower Saxony may never be fully understood, notwithstanding the recent release of documents from the *Land* archives that Tiggemann relies on.

nuclear power should play in Germany. Up until 2012, this issue divided the major political parties and raised significant obstacles for the proposed repository.

As this report considers in the previous section, surface-based investigations at Gorleben began in 1979. The Federal implementer and its construction contractor, DBE, behaved like good neighbors. Visitor centers were built; community residents constituted 80 percent of the new hires; and infrastructure improvements were made. Compensation was paid to landowners, whose mineral rights were disturbed. Tax revenues were used to offset claims that the repository caused negative economic impacts. A survey done in the early 1980s showed that 75 percent of the local population was, indeed, supportive of the repository. A second survey done in 1987 revealed roughly the same level of approval (ERC 1989:II.2-12). However, the decision in 1988 to construct a "pilot plant," licensed only under the Mining Law not the Atomic Energy Act, drew sharp criticism from local residents. Nonetheless, site characterization proceeded at a brisk pace. By 1996, two shafts had been constructed and almost 7,000 meters of drifts had been excavated.

For many interested and affected parties, the process that led to Gorleben's selection appeared to be arbitrary and technically unsupported (Appel 2006; Hocke and Renn 2009). Those views initially had little effect on either the Federal or the *Länder* governments. However, in the aftermath of the Federal election in 1998, which brought to power the Social Democrats in coalition with the Green Party, the critics now governed. As the discussion above about AkEnd details, the two parties negotiated a consensus agreement that included their common views about Gorleben.

In June 2000, agreement was reached between the Federal government and four nuclear utilities. After conceding that the site had a larger volume of suitable rock than initially expected, that the rise in the salt dome was slower than projected, and that no appreciable pockets of gas, water, or condensates had been found, the document enumerated five specific area where "doubts" had been raised.

- Gases from the corrosion of the waste could cause problems.
- Retrievability of the waste needed to be considered.
- The salt disposal concept should be compared with other disposal concepts.
- Long-term recriticality needed to be investigated.
- Regulatory requirements needed to be written concerning inadvertent human intrusion.

Because "further exploration of the Gorleben salt dome cannot contribute to the clarification of these outstanding questions," a moratorium, which was slated to last three to ten years, was put in place (quoted in IEG 2001:30). In fact, except for a brief period in late 2010, when the Christian Democrats regained sole power, the moratorium has not been lifted.

United States

Under the NWPA passed in 1982, DOE had an unambiguous obligation to select a site for a second repository.[159] The Act also limited the amount of HLW and SNF that could be disposed of in the first facility until such time as the second one was in operation.[160] As this report observes in the previous section, DOE's Second Round efforts elicited heated reactions.

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159 NWPA Section 112(b)(1)(C)

160 NWPA Section 114(d)

In accordance with the provisions in the NWPA, in the spring of 1986, DOE conducted 38 public hearings in the vicinity of the 12 potentially acceptable and eight back-up sites identified in the draft *Area Recommendation Report for the Crystalline Rock Project* (DOE 1986a). (See Table 4 on page 51.) Approximately 18,000 individuals attended those sessions; DOE also received more than 3,000 written submissions. A content analysis of the public statements presented at the hearings held in four of the seven states offers insights into the attitudes and beliefs of those who gave testimony (Kraft and Clary 1993).[161]

The hearing participants were well-informed; two-thirds of those providing a statement exhibiting moderate-to-high understanding of the nuclear waste disposal issue. But whether familiar or unfamiliar with the matter, 70 percent opposed the conclusions contained in DOE's *Recommendation Report* and less than one-half of 1 percent supported siting a repository within their state. Although strongly opposed to the implementer's decisions, the responses were relatively unemotional. Fewer than a quarter of the statements discussed nuclear waste issues in personal terms, and less than 15 percent threatened to block DOE's access to the state or place DOE officials at risk.

More than three-quarters of the remarks addressed at least one technical issue, including the view that waste disposal technology was unproven, that there was limited understanding of the geology of rock formations, and that site characterization involves many technical uncertainties. On average, two technical issues were addressed in each response. Of the top ten technical issues presented in the testimony, six issues were each mentioned by more than 20 percent of the participants. Taken together, the comments focused on the risks associated with developing a repository and on DOE's shortcomings in analyzing those risks.

But the public's objections were not limited to questioning the implementer's technical claims. Concerns were raised about intergenerational equity, stewardship over the environment, and the federal government's commitment and responsiveness. Nearly one-quarter of the responses linked their opposition to their antipathy toward nuclear power in general. These social and political issues were raised as frequently as the technical ones.

What stands out in this analysis is the role trust plays in structuring individuals' comments. Nearly 60 percent of the statements explicitly noted that DOE lacked credibility compared to two percent for EPA and one percent for state government. A multiple regression using as a dependent variable opposition to DOE's conclusions in the *Recommendation Report* suggests the power of distrust. Disparagement of DOE's credibility was four times more important in "explaining" this opposition than were NIMBY sentiments. It is noteworthy that distrust was eight times more important than reservations about DOE's competence.

An article by a *New York Times* correspondent living in Hillsboro, New Hampshire, probably captures the mood at least as well as the cold statistics.

> We are feeling the effects of the preliminary decision to consider our town for a nuclear dump. Dozens of real-estate deals fell through. Building plans were postponed. We are a town held hostage—not by foreign terrorists, but by our own Government.

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[161] Content analysis is a standard methodology used broadly in the social sciences. It is a technique for analyzing and interpreting artifacts of social communication, such as newspaper and television reporting, speeches, and written documents. The reliability and validity of the analyses must always be questioned. But if done carefully, it can yield important insights. Altogether, the researchers analyzed the testimony of 1,045 individuals.

> Not just economically, but emotionally, too, many of us are devastated—plunged into a period of terrible fear and uncertainty, our lives disrupted, as we frantically pursue alternatives, challenge the Government's site-selection process, and await the outcome.[162]

This intense opposition arose, in part, because DOE officials appeared to be tone-deaf to the real-world implications of the technically elaborate winnowing process that they had adopted.[163] As one commentator put it: how could the implementer identify a batholith under Sebago Lake in Maine—the source of Portland's drinking water—as a potentially acceptable site? But state officials were certainly well aware of the climate of opinion.

When Herrington announced the indefinite suspension of the Second Round because the volume of SNF being produced was less than anticipated, he maintained that politics never entered into his decision. More than a few skeptics raised their eyebrows.[164] Indeed, barely a month earlier the head of DOE's waste-management program had told a congressional subcommittee that a second repository would definitely be needed.

But Herrington's announcement, if not its underlying intent, certainly did ease the Reagan Administration's concern that the Republicans would lose control of the Senate in the 1986 election (Carter 1987:411). Four senators from the Second Round states of Wisconsin, New Hampshire, Georgia, and North Carolina would not have to defend an administration decision that was overwhelmingly unpopular. Moreover, the reelection prospects of New Hampshire's Governor John Sununu, who had to become a vocal critic of DOE's siting process, were strengthened.

A bipartisan group of 13 congressmen wrote Herrington, arguing that his decision "could destroy the delicate balance and might ultimately lead to the erosion of" the NWPA.[165] Beyond that fear, as Herrington acknowledged ten months later in testimony to Congress, the decision violated the law and would be reversed.[166] Two months after that, DOE announced that, rather than being postponed indefinitely, the Second Round would begin again in 2007 and that the repository would begin operation in 2016.

In parallel with the controversy surrounding the Second Round, DOE had to address a congressional challenge to its decision winnowing down the five potentially acceptable sites for the first repository. As this report discusses in the previous section, DOE adopted a sophisticated decision-aiding methodology, multiattribute utility analysis (MUA). To exercise that technique, DOE officials inevitably had to use their discretion to weight the important various considerations used to winnow down the choice. Based solely on that weighting, the composite rank order was Yucca Mountain, Richton Dome, and Deaf Smith County. Yet, in Herrington's site-recommendation report to President Reagan, he eliminated the Richton Dome site and substituted the Hanford one. His decision, he explained, was based on judgments that, in effect, reduced the weighting placed on cost, reduced of the weighting placed on projected *differences* in performance, reduced the weighting of transportation costs, and increased the weighting placed on geologic diversity (DOE 1986d).

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162 Joyce Maynard, "The Story of a Town," *New York Times Magazine*, May 11, 1986.

163 One of the DOE officials who were responsible at the time maintains that this tone-deafness demonstrated how objectively they implemented the site-selection process.

164 See, for example, Eliot Marshall, "Nuclear Waste Program Faces Political Burial," *Science* 233, August 22, 1986, 835-836.

165 Quoted in Colglazier and Langum 1988:333.

166 See Colglazier and Langum 1988:333 and Easterling and Kunreuther 1995:40.

For the chairs of two subcommittees in the House of Representatives, Jim Weaver and Edward Markey, this explanation did not ring true. Following an investigation, the subcommittee staffs presented their preliminary results, among which were these findings:[167]

- DOE officials systematically deleted passages from the MUA report that were critical of the Hanford site.
- DOE officials systematically deleted passages stating that the Richton Dome, Mississippi, site was superior to the Deaf Smith, Texas, site.
- DOE officials assigned an inappropriately low weighting to postclosure safety.
- DOE officials ignored legal advice that the choice of only one non-salt site would satisfy the legislative and regulatory requirements for geologic diversity.

At its core, the criticism was that DOE should have made its weighting choices clear at the start, used them to drive the MUA, and stuck with the results.

Weaver and Markey, now joined by Congressmen Ron Wyden and Al Swift, wrote Herrington in October 1986. Their letter incorporated the subcommittee staffs' findings. Summarizing their position, they told the Secretary that:

> The decision to select a permanent waste repository must be based on the soundest scientific and technical judgments possible. Yet we have found conclusive evidence, in many cases supplied by DOE's own internal documents, which leads us to only one possible conclusion: DOE distorted and disregarded its own scientific analysis in order to support selection of the Hanford, Washington site and to avoid selection of the Richton Dome, Mississippi site.[168]

DOE responded to the congressmen in a ten-page February 1987 letter. It maintained that many of the so-called deleted passages in fact appeared elsewhere in the MUA report. Moreover, it rejected the claim that geologic diversity drove the Secretary's decision; Hanford had the lowest adverse impacts on the community and on the environment in the vicinity of the site. Further, to have included geologic diversity explicitly would have required a different portfolio-effects analysis, which would have taken considerable time.

But at the heart of DOE's rejoinder was the view that the congressmen had fundamentally misunderstood the role an MUA can, and should, play.

> [Your] statements indicate a belief that the MUA is capable of providing a "scientific" ranking of the five nominated sites—a ranking somehow devoid of *judgment*—which should then be used as the sole basis for selecting three for characterization. Without this fundamental premise, there are no logical grounds for criticizing DOE for not selecting the three top-ranked sites identified by the MUA or for inferring that DOE "ignored" the results of the MUA. Indeed, without this premise, there is no incentive for DOE to engage in all of the "manipulation" and "distortions" you believe were undertaken to promote Hanford into the top three sites [emphasis added].[169]

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[167] Memorandum from Subcommittee Staff to Jim Weaver, Chairman, Subcommittee on General Oversight, Northwest Power, and Forest Management, Committee on Interior and Insular Affairs, and Edward Markey, Chairman, Subcommittee on Energy Conservation and Power, Committee on Energy and Commerce, October 20, 1986.

[168] Letter from Jim Weaver, Edward Markey, Ron Wyden, and Al Swift to John Herrington, October 20, 1986.

[169] Letter from Ben Rusche, Director of the Office of Civilian Radioactive Waste Management, Department of Energy, to Congressman Edward Markey, February 18, 1987, 2.

Ultimately, the Weaver/Markey challenge faded away as Congress refused to question DOE's exercise of discretion.

Immediately after DOE identified five sites that were suitable for characterization in 1985, the affected states challenged in court DOE's promulgation of the *Siting Guidelines*.[170] But that case was dismissed as premature; no final agency action had been taken. But once President Reagan in May 1986 chose the final three, the matter ripened. Nevada, Texas, and Washington soon filed lawsuits to overturn that decision.

The key lawsuit was *Nevada v. Watkins*.[171] Between the time that the complaint was filed and the time when briefs had to be submitted, Congress had passed the Nuclear Waste Policy Amendments Act. Thus, for the purposes of this discussion, only one of the Nevada's objections is relevant: whether DOE carried out a legally defensible process for disqualifying a candidate site.

In the state's view, notwithstanding the 1987 legislation, Yucca Mountain was clearly disqualified under the *Siting Guidelines*. But for those guidelines to be meaningful,

> The Secretary must have a methodology, some formalized system of data collection, evaluation, and decision-making, to determine, *early and throughout the process*, whether or not any Disqualifying Condition exists, and if so, for making the required determination to terminate work at the site whenever such a condition is found [emphasis added].[172]

In essence, the state argued that the Secretary of Energy had a judicially enforceable duty to assess continuously whether a candidate site should be eliminated. The court held to the contrary; the statute commits the timing of the Secretary's suitability determination to his discretion. "The Secretary has not determined whether disqualifying conditions exist, preferring instead to pursue further study. This decision is not reviewable."[173]

With respect then to the Weaver/Markey tempest and to Nevada's lawsuit, DOE's strenuous efforts to retain discretion when crafting and implementing the *Siting Guidelines* were rewarded. They powerfully facilitated the passage of the President's selection of three candidate sites through the Social Acceptability Filter. Yet, the process left a bad taste in the mouths of many interested and affected parties in the affected states and, for them, drew down further DOE's reservoir of trust and confidence.

Consent-Based Siting Processes

As the 15 historical cases just detailed make abundantly clear, passing sites through the Social Acceptability Filter poses substantial challenges, so much so, that national waste-management programs in recent years have increasingly adopted what is being called "consent-based" site-selection strategies. Indeed, the BRC recommended that the United States adopt such an approach when siting deep-mined, geologic repositories in the future (BRC 2012). This generic label, however, masks substantial differences among countries on some critical questions:

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170 See, for example, *Nevada v. Herrington*, 777 F.2d 529 (9th Cir. 1985).

171 *Nevada v. Watkins*, 914 F.2d 1545 (9th Cir. 1990), *cert. denied*, 111 S.Ct. 1105 (1991). After the passage of the 1987 Nuclear Waste Policy Amendments Act, the Texas and Washington lawsuits faded away.

172 Petitioner's Opening Brief at 67.

173 *Nevada v. Watkins* at 1564.

- Who consents?
- What motivates the consenter?
- What is consented to?
- Through what mechanism is consent expressed?

This subdivision of this report describes those differences as well as others and considers the conditions that affect whether consent-based siting strategies succeed or fail.

This discussion begins with the case of Canada, where the site-selection process is at an early stage, and continues chronologically with the cases of WIPP, Finland, France, and Sweden. The narrative concludes with an examination of consent-based siting in the United Kingdom and Japan, where the original strategy needed to be revisited and revised significantly.

Canada

In October 1994, Atomic Energy of Canada Limited (AECL) published an EIS in support of implementing a disposal concept in the crystalline rock of the Canadian Shield (AECL 1994).[174] A review panel (now known as the Seaborn Panel) conducted a series of public meetings beginning in March 1996. Two years later, the panel submitted its report to the Canadian Government (Seaborn Panel 1998). The key conclusion reached was that:

> From a technical perspective, safety of the AECL concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it has not. As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support. The concept in its current form does not have the required level of acceptability to be adopted as Canada's approach for managing nuclear fuel wastes (Seaborn Panel 1998:2).

In December 1998, Canada's Federal Government accepted the panel's central findings and recommendations and, in November 2002, brought into force the Nuclear Fuel Waste Act, which established NWMO. The new implementer interpreted its mission broadly: "To develop collaboratively with Canadians a management approach for the long-term care of Canada's used nuclear fuel that is socially acceptable, technically sound, environmentally responsible, and economically feasible" (NWMO 2005:17). Given the fate of the AECL effort, mentioning the "social" first and the "technical" second was not likely a random choice of wording. In an unparalleled fashion, the analysis of how to ensure "community well-being"—a prerequisite for encouraging localities to come forward and participate in the siting process—pervades the report.[175]

Importantly, it was not NWMO's vision that structured all of the analyses. To learn about Canadian beliefs, values, and attitudes, the implementer undertook to engage them using a wide range of participatory methods. This commitment to using a variety of techniques stemmed from one of NWMO's core tenets: ensuring that a "diversity of voices" contributed to its work.

[174] The EIS, it should be stated, was never intended to present a framework for siting.

[175] As this report details in the previous section, detriment to community well-being became part of the Exclusion Criteria that NWMO uses to select sites. It was explicitly evaluated during the Phase 1 Preliminary Assessments and became the basis for not carrying several communities forward in the siting process.

At the center of NWMO's engagement strategy is the idea of "dialogue," not one-way communication, with interested and affected parties. The dialogue process as implemented sought direction from Canadians on the following points (NWMO 2005:60):

- What questions should be asked and answered in the study, and what are the key issues to be addressed in the assessment of management approaches?
- What range of technical methods should be considered in the study?
- How should the risks, cost, and benefits of each management approach be assessed?
- What should be the overarching management structure and implementation plans for each management approach?

Figure 25 illustrates the approaches taken to incorporate public views.

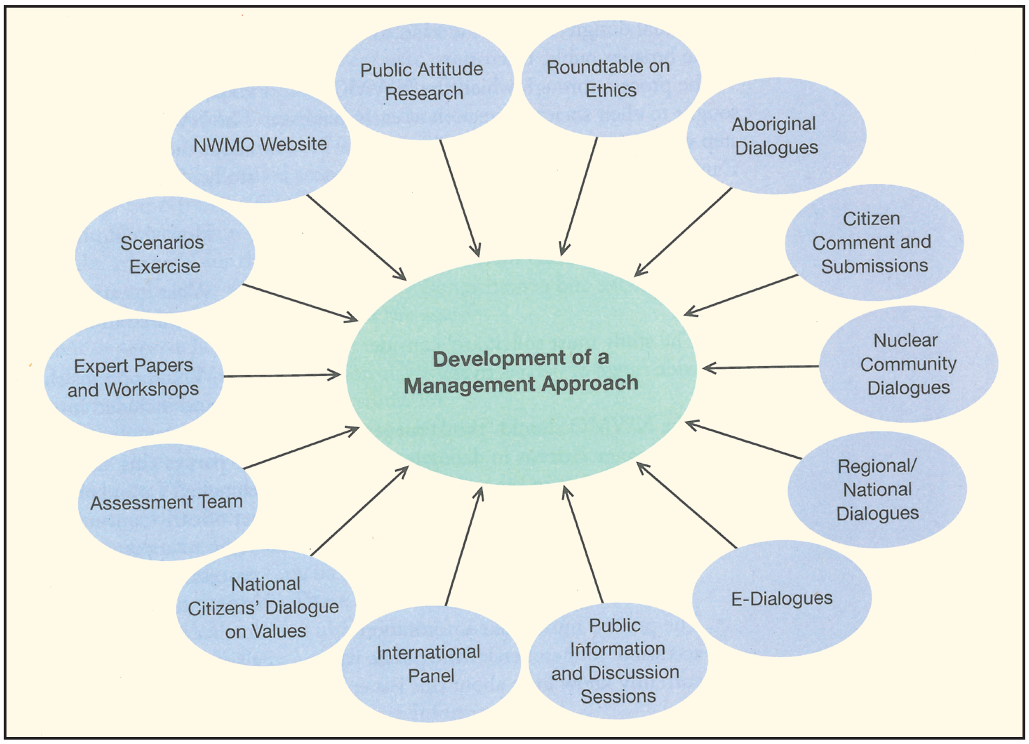

Figure 25. Techniques used to elicit the beliefs, values, and attitudes of the Canadian public (Source: NWMO 2005)

Perhaps as impressive as the efforts that were made to learn about the views of Canadians has been NWMO's success in creating an organizational culture that appears to place a high priority on openness, responsiveness, and sensitivity. Although the Adaptive Phased Management siting process is still in its earliest stages, judging by the results so far, NWMO has enjoyed a high degree of success. Twenty-two communities initially expressed an interest in learning more about the implications of hosting a deep-mined, geologic repository for HLW and SNF. They consented to desk-based studies and preliminary site investigations. Thirteen are no longer being considered. None of those made the decision to withdraw on their own volition.[176]

[176] Nipigon did write a letter to NWMO informing them of its intention to withdraw. But that decision followed early investigations that raised serious questions about the availability of a technically suitable site within the community.

NWMO's leaders recognize that the siting process is fragile. Any major misstep could destroy the reservoir of trust and acceptance that the organization has so carefully sought to create. It remains to be seen, of course, whether the remaining potential sites can pass through the Technical Suitability and Social Acceptability Filters in the future. But cautious optimism may be the appropriate opinion to hold at least for now.

United States

As this report discusses above in the section on the Technical Suitability Filter, the stimulus that directed the AEC to southeastern New Mexico in 1972 came from the community leadership in Carlsbad and Eddy County. (See Box 6 on page 45.) Without persistent and strategic local involvement over a period of two decades, it is unclear whether WIPP would ever have been developed and brought into operation. As to why the town fathers were so intent on siting the facility nearby, one observer noted:

> [T]he backyard in question was windblown, semi-arid plain of scrub brush and red sand. … This was no agricultural cornucopia of the kind found on the Texas High Plains. The soils were poor, and there was no prolific aquifer to irrigate them. (Carter:1987:178).

Moreover, the local potash industry, which once dominated the market in the Western Hemisphere, shrank precipitously starting in 1968. Clearly, a new economic driver had to be found to replace it.

But local support by itself was insufficient to pass WIPP through the Social Acceptability Filter. Two strands of events, which played out in parallel, had to arrive at successful outcomes as well.[177] First, DOE and the State of New Mexico had to agree to a *modus operandi*. Second, Congress had to pass legislation permanently withdrawing the land from public use.

The bulk of New Mexico's population resides along the Albuquerque/Santa Fe axis. Although the AEC has two major facilities in that area—Los Alamos and Sandia National Laboratories—public attitudes, to the extent they had formed, were at least skeptical if not opposed to siting a repository in the state. At the same time, the economic downturn in southeastern New Mexico could not be ignored. Thus, the state never voiced strong objections to the early siting activities. But getting the state on board affirmatively required that WIPP's mission be unambiguously defined, that a formal "consultation and cooperation" agreement be negotiated, and that independent technical reviewers evaluate the investigations and studies conducted first by ERDA and then by DOE.

The initial exchanges between the state and DOE were anything but auspicious. ERDA originally had defined the facility's mission as disposing of transuranic waste from the nuclear weapons complex. In late 1977, the newly created DOE, without informing the state, began exploring the idea of using WIPP to dispose of defense HLW as well. In February 1978, the state's congressional delegation, headed by Senator Pete Domenici, paid a visit to DOE Secretary James Schlesinger. Schlesinger assured the state officials that a repository would not be built over New Mexico's objections. Three months later, however, DOE released a study, led by John Deutch, then DOE's Director of the Office of Energy Research (DOE 1978). The document recommended that experiments at WIPP should be deployed to demonstrate

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177 This discussion draws heavily on Carter 1987, McCutcheon 2002, and Stewart and Stewart 2011.

the safety of disposing SNF and that transuranic waste should be disposed of irretrievably.[178] Again, the state was not notified about these recommendations beforehand.

Ultimately, it was Congress, and especially Melvin Price, Chairman of the House of Representatives Armed Services Committee, who had the final word. He opposed any commercial waste coming to WIPP, fearful that NRC might then have to license the facility, as required under the 1975 Energy Reorganization Act. In his view, civilian interference in military operations could not be tolerated. The 1979 legislation that authorized the construction of WIPP limited its mission to the disposal of defense transuranic waste.[179]

The 1979 law also structured how power would be distributed between the state and the central governments. Schlesinger's off-the-cuff proposal of a state role in determining WIPP's future served only to muddle the situation, not clarify it. Asked for their advice, DOE's attorneys maintained that the agency did not have the legal authority to offer the state a formal decision-making role, a position to which the congressional Government Accounting Office later concurred. Moreover, just as Price was determined to prevent NRC from licensing WIPP, he was equally adamant that the state should not have a decisive role. In this regard, he differed with Domenici, who believed that the state needed to protect its interests. Out of this disagreement came a compromise in which the Interagency Review Group on Nuclear Waste Management's idea of state "consultation and concurrence" morphed into "consultation and cooperation."

The committee report on the 1979 law held out hope that a consultation and cooperation agreement could be quickly reached. But by August 1980, negotiations had reached an impasse, and New Mexico's Attorney General, Jeffrey Bingaman, declared that draft language put on the table by DOE was legally deficient in protecting New Mexico's rights. The following May, he filed suit in U.S. District Court claiming, among other things, that DOE had proceeded with WIPP's development absent the state's concurrence. Within six weeks, however, a settlement was negotiated, which, although modified twice, remains an important element governing the relationship between DOE and New Mexico with respect to WIPP.[180]

From the early beginnings of the WIPP project, the state sought to develop a capacity to independently review the technical investigations carried out first by ERDA and then by DOE. In 1975, Governor Jerry Apodaca established an advisory committee on WIPP. Some of its members, however, were employed at DOE national laboratories, creating a possible conflict of interest with their advice.

In 1978, DOE agreed to support and fund an independent technical overseer, the Environmental Evaluation Group (EEG), which would assist the state's Environmental Improvement Division. Over the years, the EEG walked a narrow line, rebuffing both WIPP's proponents and opponents, but largely retaining its credibility with both. By 1983, its competence and political neutrality gave it space to reach what otherwise would been a

178 A recommendation in the IRG report to construct an unlicensed repository demonstration project using 1,000 SNF assemblies inadvertently fueled New Mexico's concern.

179 Just to make certain that there was no misunderstanding, the 1992 WIPP Land Withdrawal Act explicitly prohibited commercial SNF from entering the facility.

180 In December 1982, DOE promised to seek funds to upgrade transportation routes leading to WIPP. The first modification to the consultation and cooperation agreement in November 1984 committed DOE to comply with all applicable local, state, and federal regulations, including radiation protection standards promulgated by EPA.

controversial conclusion that the site had "been characterized in sufficient detail to warrant confidence" in its safety (O'Neill et al. 1983:135).[181] Precisely because of the credibility that the EEG had built up over the years, this conclusion strongly influenced policymakers and attentive members of the general public.

WIPP sits beneath public lands. In order for a site to be developed as a repository, that territory had to be withdrawn from public use. The Bureau of Land Management (BLM) within the Department of the Interior controlled the decision to do so. ERDA filed a request in 1976 to bar public entry for two years to over 17,000 acres of land in Eddy County. It renewed its application in 1978. BLM approved each petition in less than a month.

Two years later, BLM concluded that it had the authority to permit DOE to sink boreholes and mine out drifts. In April 1981, the two agencies signed a cooperative agreement that allowed those *in-situ* characterization activities to be conducted. In March 1982, BLM extended its land withdrawal order for eight more years. By that time, the question of land withdrawal had evolved from a routine bureaucratic exercise into a highly charged political issue. Environmental groups filed lawsuits, which were ultimately unsuccessful, challenging both DOE and BLM. But it was becoming increasingly clear that land withdrawal would ultimately have to be addressed by Congress.

The first legislation was introduced in 1987 by Domenici and Bingaman (by then a senator) and two Republican congressmen, Joe Skeen (who represented Carlsbad) and Manuel Lujan. It never passed, in part because it did not satisfy the concerns of the fifth delegation member, Democrat Bill Richardson.[182] Meanwhile, officials from states hosting the nuclear weapons complex—Washington, Colorado, Idaho, and South Carolina—were growing more impatient with the delay. They wanted the transuranic waste stored in their states transferred to New Mexico.

DOE Secretary James Watkins, who took office in January 1989, shared their frustration and proposed his own land withdrawal legislation. The New Mexico delegation was now unified in dismissing it because it permitted *in-situ* site investigations using radioactive material, because it did not require the completion of a safety analysis report, and because it failed to provide nearly $200 million for road improvements.[183] Watkins forced the issue by requesting administrative land withdrawal, a bid that Lujan (now Secretary of the Interior) approved in January 1991.

Predictably, New Mexico's Attorney General, then Tom Udall, joined by four environmental groups, three congressmen, and the State of Texas, sued the Departments of Energy and Interior. In November 1991, the U.S. District Court judge granted the plaintiffs a preliminary injunction. This decision seemed to break the congressional logjam.

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181 At the request of Domenici, the NAS created the WIPP panel, chaired by Konrad Krauskopf. It visited the facility for the first time in April 1983. The state's opinion of that reviewer was more ambivalent than its opinion of the Environmental Evaluation Group.

182 Bingaman, Lujan, and Richardson would later play important roles in the WIPP saga—Bingaman as chair of the Senate Energy and Natural Resources committee for nearly two decades, Lujan as Secretary of the Interior, and Richardson as the Secretary of Energy that authorized the first waste shipment to WIPP.

183 The issue of *in-situ* testing using radioactive materials was a major distraction during the 1989-1992 period. The NAS WIPP panel went back and forth on whether the tests were technically defensible. In a June 1992 letter to DOE, the panelists said that there was "no discernible scientific basis" for the tests. Notwithstanding that language, NAS President Frank Press wrote the chairmen of key congressional committees to "assure them of the panel's continued support" for DOE's underground testing program.

The WIPP Land Withdrawal Act was approved by overwhelming majorities in each house. President George H. W. Bush signed it into law on October 30, 1992. The legislation gave EPA the authority to "certify" whether DOE's safety assessment complied with the regulator's environmental standard. It permitted *in-situ* testing that was "directly relevant to the certification of compliance" but allowed EPA to approve any DOE testing plans.[184] It required DOE to develop procedures for retrieving any emplaced wastes and for decommissioning the facility. It explicitly prohibited the disposal of HLW and SNF at WIPP. It granted New Mexico annual payments of $20 million for 15 years for transportation infrastructure improvements.

Twenty years after ERDA scientists came to southeastern New Mexico, the WIPP site passed through the last Social Acceptability Filter. Certifying that WIPP satisfied EPA's environmental standard, however, would take another six years.[185]

EPA's review of whether WIPP could pass through the final Technical Suitability Filter benefited from a substantial body of technical analyses that had been conducted over the previous 15 years. DOE finalized an EIS for WIPP in 1980 (DOE 1980b). The EEG had concluded that the site-characterization efforts had been sufficient to provide confidence in the planned repository's safety. DOE finalized a Supplemental EIS in 1990 (DOE 1990). Sandia National Laboratories developed a performance assessment for WIPP in 1992 (Sandia 1992). DOE used this analysis to prepare a draft Compliance Certification Application (CCA) in 1995 (DOE 1995), which the NAS WIPP Panel reviewed the next year (NAS 1996).

EPA needed to certify that DOE's application demonstrated that the planned WIPP repository satisfied, with reasonable expectation, two EPA regulations:[186]

- *Standard for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes*, 40CFR191, the generic environmental standard for deep-mined, geologic repositories
- *Criteria for the Certification and Determination of the Waste Isolation Pilot Plant's Compliance with Environmental Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes*, 40CFR194, which addresses the specific application of 40CFR191 to WIPP

EPA received DOE's 72,000 page CCA in October 1996. In May 1997, EPA informed DOE that its application was complete, thus starting a one-year clock on the regulator's review.

By then most of the technical issues had been well-defined. These included (see NAS 1996):

- System design, including shaft seals and panel closures
- Scenario development, including specification of human intrusion
- Regional groundwater flow
- Solute transport
- Physical retardation of the radionuclides via matrix diffusion
- Chemical retardation of the radionuclides

[184] In October 1993, President William Clinton's Secretary of Energy, Hazel O'Leary, announced that DOE no longer intended to conduct *in-situ* tests using radioactive material.

[185] What follows relies on NAS 1996, Rechard 2000, McCutcheon 2002, and Stewart and Stewart 2011.

[186] Initially, EPA had to consider compliance with a third regulation (40CFR268), derived from the Resource Conservation and Recovery Act (RCRA), which dealt with the management of hazardous waste. Legislation passed in 1996, however, exempted WIPP from this regulation. However, the facility would still have to meet New Mexico's RCRA requirements.

- Confidence in the site-characterization data that were used to construct the underlying performance assessment that projected WIPP's behavior over 10,000 years

In October 1997, EPA published a Notice of Proposed Ruling, indicating that it was prepared to determine that DOE satisfied relevant regulatory requirements. To obtain public input on that tentative conclusion, the regulator sought written comments and held three public meetings in Carlsbad, Albuquerque, and Santa Fe, New Mexico, and Washington, DC, in December 1997 and January 1998.

On May 18, 1998, EPA issued its Final Rule under 10CFR194 (EPA 1998). It found that:

> WIPP complies with the containment requirements by a comfortable margin, even when using more conservative parameter values that were changed significantly from those in the CCA performance assessment. This modeling shows that the WIPP will contain waste safely under realistic scenarios and even in many extreme cases (EPA 1998:27,398).

Although DOE had complied with the two regulations, the regulator imposed four conditions.[187] Moreover, going forward, DOE has to submit annual reports on new activities or conditions at WIPP, and, as required by the Land Withdrawal Act, EPA must recertify WIPP's regulatory compliance every five years.[188]

WIPP received its first shipment of non-RCRA transuranic waste, which constitutes about 40 percent of the total DOE inventory, from Los Alamos National Laboratory on March 26, 1999. Later that same year, the State of New Mexico began its deliberations on whether WIPP should be issued a RCRA permit, an action it took in October 1999. WIPP operated continuously until early 2014, when two accidents, one of which released radionuclides to the environment, forced DOE to halt operations.

Finland

In Finland, the siting of a repository is the responsibility of the reactor owners. TVO owns the two Olkiluoto reactors located outside of Eurajoki on the west coast, and IVO (later called Fortum Power and Heat Ltd.) owns the two Loviisa power plants located outside of Hästholmen on the east coast. IVO bought its two reactors from the Soviet Union, and, under the terms of the purchase contract, the SNF from those two units was repatriated until 1996, when the arrangement was terminated by the Finnish Parliament. Just prior to that time, TVO and IVO created an implementing organization, Posiva Oy, with the assignment to jointly develop a repository facility.[189] Under Finnish law, Government and then Parliament must approve the choice of repository site by passing what is called a "Decision-in-Principle." Since 1987, under the Nuclear Energy Law, the local community has possessed an unconditional veto power over that action.

As this report discusses in the previous section, TVO identified five potential sites in 1987: Eurajoki, Kivetty, Romuvaara, Veitsivaara, and Syyra. The last two were eliminated in 1992

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[187] One of the conditions dealt with the panel closure system, which was intended over the long term to block brine flow between the waste panels. Two of the conditions were related to activities conducted at the waste-generators sites. The final condition required DOE to submit a schedule for instituting passive institutional controls, including markers and plans for preserving records.

[188] Section 8(f)

[189] A third utility, Fennovoima, has proposed to build a reactor in northern Finland near the community of Phyajoki. It is negotiating with Posiva Oy over whether Fennovoima's SNF could be disposed of in the joint facility. Those negotiations have been taking place for several years.

because of their technical complexity. Posiva Oy added Hästholmen five years later. (See Figure 10 page 39.) Preliminary conversations with local authorities indicated that none of the four remaining communities would use their veto power.

The implementer conducted a public opinion survey in 1999, which revealed that more than 50 percent of the general public in Kivetty and Romuvaara would not accept a repository within their boundaries. Support in Hästholmen was higher but not as strong as in Eurajoki. For reasons that this reports details in the previous section, Posiva Oy decided to choose the Eurajoki site in early January 2000. Three weeks later, the councilors of the municipality voted 20 to seven to approve a positive statement for the Decision-in-Principle.[190] They arrived at that position through a protracted process, during which they had to react to the possibility that the municipal veto might be taken away and that Posiva Oy might choose to construct the repository elsewhere in the vicinity, thereby resulting in a significant loss of tax revenue.[191]

In 1973, when Eurajoki decided whether to approve the construction plan for the first Olkiluoto reactor, it did so on the condition that SNF would not be buried in the nearby bedrock. Six years later, when the construction plan was extended, the municipal council required TVO to reaffirm its commitment that "final disposal of HLW and SNF would not take place in the area" (quoted in Kojo 2006:53). But when discussions fell through about possibly reprocessing the SNF in 1980, the community realized that the potential for the waste to remain onsite had become a very real one.

Still, the preponderance of local opinion opposed the siting of the repository in Eurajoki. In December 1992, the following sentence was added to the 1993-1997 Communal Report: "The council must act so that no final disposal of high-activity nuclear fuel will take place in Eurajoki municipality." Two years later, the sentence was removed. "The political attitude of the Council of Eurajoki concerning the siting of the repository was neutralized" (quoted in Kojo 2006:55). By then, the manager of the Loviisa plant had broached the idea that, if a voluntary agreement could not be reached, a compulsory approach might have to be adopted. Moreover, three municipalities near Eurajoki—Rauma, Kannonkoski, and Rautavaara—indicated that they might support the construction of a repository, which would bring in at least the equivalent of $1.5 million per year in property taxes.

Whether those threats would have materialized under different circumstances is an open question. But what is clear is that Eurajoki was heavily and increasingly dependent on TVO and Posiva Oy to fund municipal activities. A law passed by the Finnish Parliament in 1990 shifted the main source of local revenue from a business income tax to a property tax. Given that TVO paid one-third of the locality's taxes even before 1990, the necessity to maintain productive relations with the utility was obvious. Led by councilors from the National Coalition Party, the local government and TVO in 1995 signed a cooperation agreement, which called for compensation in return for the municipality accepting the Decision-in-Principle.

As conversations proceeded over the next four years in several fora, the Vuojoki working party, named after the old-age home in the town, was formed.[192] It held its first meeting in

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190 The Decision-in-Principle came into force in May 2002.

191 What follows relies heavily on Kojo 2006 and Kojo 2008.

192 The working party initially consisted of nine members: five from the municipality, two from TVO, and two from Posiva Oy. It was later expanded as the deliberations become more intense.

August 1998. Soon thereafter, the working party received from the local council strong signals of the shifting political tides. The governing body endorsed a strategic plan calling for Eurajoki's citizens to gain a "sufficiently large and long-term compensation for siting of the final disposal repository in the locality. … With time, a high-level international research, training, and visitors' center will be created" (quoted in Kojo 2006:60).

The working party's report to the council laid out the basic terms of the compensation: Posiva Oy would lease the Vuojoki Mansion and loan money to Eurajoki to construct a new old-age home. The rent received on the lease would be used to repay the loan. The council then negotiated with Posiva Oy on the modalities. The final agreement included funding by TVO to build a new ice rink.

How well did the municipality fare in the bargaining surrounding a commitment to accept the Decision-in-Principle? Given its relatively weak negotiating position, probably quite well. TVO and Posiva Oy were still contemplating the possibility of developing the repository at Loviisa as late as September 1999. The Eurajoki municipality had few resources to organize local study groups or to gather information independently. But, most of all, the municipality could not disguise the fact that it had become financially dependent on the choices that Posiva Oy would make. From Eurajoki's perspective, a steady stream of income for generations to come seemed like a good deal.

One possible side effect emerged from the 25-year-long engagement process between the Eurajoki community and TVO/Posiva Oy. In 1984, 60 percent of the local population disagreed with the statement that "final disposal in the Finnish bedrock is safe." Only 17 percent agreed. In 2008, 34 percent disagreed, and 41 percent agreed (Kari et al. 2010:69).

France

In France, Christian Bataille, the mediator appointed in accord with the 1991 Research on Radioactive Waste Management Act, began his assignment in August 1993 to identify a community willing to host a URL. Included with that willingness was an understanding that, if the geology proved to be suitable, a repository might be developed in the area. Of the 30 *départements* that showed initial interest, only eight could meet the geologic criteria set forth by the regulator, ASN. As this report discusses in the previous section, preliminary conversations with community leaders and additional technical investigations winnowed the eight down to four: Gard, Vienne, Meuse, and Haute-Marne.[193]

In an effort to stimulate discussions with communities, Bataille ensured that the Local Information and Oversight Committees (CLIs) would be formed and would operate at a much earlier stage than required by the 1991 law. The early, private interactions with officials in three of the four *départements* suggested that the localities would be quite receptive to a facility.

The exception was Gard. That *département* is the home of the French nuclear complex, Marcoule. It is also where fine French wine is produced. As long as public attention was not called to the nuclear site, the two activities coexisted. (A Rhône Valley wine carries the name Cuvée Marcoule.) Once the *département* became a candidate for a URL, and perhaps a repository, the situation dramatically changed. At a late 1994 meeting of the Côtes du Rhône wine syndicate, concerns about the stigmatization of the product were raised. As its president put it: "[We] refuse to see our vines grow on top of a nuclear dump."[194]

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193 The other four *départements* were Allier, Inde, Marne, and Meurthe-et-Moselle.

194 Quoted in Barthe and Mays 2001:423.

Although there is some dispute over how effectively the CLIs carried out their responsibilities,[195] healthy discussions had taken place in each of the four communities by February 1997, when formal public inquiries were launched around each site. Four layers of local government—municipal, district, *département,* and region—could, at least in principle, weigh in on whether the facility should be licensed and built. Their votes, however, would not be binding on the central government.

In Gard, the debate over hosting a URL continued to center on the risks to the local wine's image. As one industry representative stated: "Wine is 40 percent liquid and 60 percent dreams."[196] ANDRA, somewhat belatedly, countered with a study and a press release in which a champagne grower, shown tending the fields near the implementer's low-level disposal site, the Centre de Stockage de l'Aube, reassured the reader that wine and nuclear waste were not incompatible.

Opinion was sharply divided as well at the hearings that took place in the Meuse *département*. As part of a legislatively mandated public inquiry, some 6,500 submissions opposing the siting were introduced. They objected to a lack of genuine participation, insufficient environmental assessments, and the appearance of being "bribed" because of the benefits package that was being offered.

In one case, the votes of the councils in the different jurisdictions exhibited the classic "doughnut" effect, whereby local governments closer to the proposed site tended to be more favorably inclined than governments that represented larger territories. The Languedoc-Roussillon regional council overwhelmingly voted 45-9 against siting. The council for the Gard *département* voted 25-13 in favor. Only seven out of the 27 municipalities surrounding the site voted against. But in Vienne and Haute-Marne, there was agreement between the region and the *département* that the facility should be approved. The regional council of Lorraine, which included the Meuse *département*, voted against, but only after the deadline for acting had passed. Meuse itself never voted.

A siting decision was anticipated toward the end of 1997. It was postponed due to upcoming elections. The next year, the government decided to remove Vienne from further consideration because of the negative findings of the CNE. It also dropped Gard, ostensibly because of seismic concerns, but political calculations also played a part. The government consolidated the Meuse and Haute-Marne investigations and focused on an area near the town of Bure.

In January 1999, ANDRA submitted a license application, as required by the 1991 law, to the Conseil d'Etat to approve the construction of the URL near Bure. Six months later, that body approved the application and sent it on to the responsible ministers for signature. The Minister of the Environment, Dominique Voynet, a Green Party member, would agree to sign only if the government made reversibility an integral part of future repository policy.[197] With the enactment of the 2006 Radioactive Materials and Waste Planning Law,

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[195] Residents of Meuse and Vienne submitted a complaint to the Conseil d'Etat, the highest administrative court, arguing the meetings were too restrictive and formal. The complaint was dismissed. For additional information about this complaint, see Van den Berg and Damveld 2000:40-50.

[196] Quoted in Barthe and Mays 2001:424.

[197] The next section of this report, dealing with the interdependence of the Technical Suitability and Social Acceptability Filters, discusses how the French Parliament made reversibility a formal site-suitability criterion.

Parliament officially declared that an area near Bure, ANDRA termed it the "transposition zone," would be the site of a reversible deep-mined, geologic repository for HLW and SNF.

Sweden

In Sweden, SKB regrouped after encountering community resistance to its plans to drill test boreholes. Between the mid-1980s and early 1990s, the implementer realized three important, but related, objectives:

- It deflected criticism from its overseers that its site-suitability criteria were too imprecise.
- It launched a new siting program in which it sought permission from the municipalities to investigate sites.
- It fundamentally reoriented its organizational culture so that it could better engage local municipalities.

Under the Nuclear Activities Act, SKB must prepare a triennial report about its Research and Development Programme. The document released in 1992 asserted that suitable sites "cannot be associated with any … particular geological environment" (SKB 1992a:70). In another document, it maintained that the "bedrock as a barrier to radionuclide transport is very limited" (SKB 1992b:xiii). Nonetheless, in reviewing the Research and Development Programme, both the Swedish regulator, SKI, and the technical overseer, at the time KASAM, now the Swedish National Council for Nuclear Waste, pressed SKB to be more specific in terms of what geologic criteria should be used to guide the search for potential sites.

The government endorsed this line of criticism and required SKB to prepare a supplement to the triennial report. When it was published in 1994, that document was still too imprecise for the regulator, but, this time, the government chose not to force the issue.

From SKB's perspective, detailing the geologic criteria ahead of time would constrain its discretion. The implementer held that safety, technology, land and environment, and society were all essential factors in deciding on a repository site. To limit arbitrarily at the start potentially promising locations was not a sound strategy.

Even before this perspective was finally accepted, SKB sent a letter to all 286 municipalities in Sweden. The letter recited the basic facts surrounding nuclear waste disposal, including the KBS-3 concept. It further observed that "feasibility studies" would be required to determine whether a site was suitable for developing a repository. If a municipality was possibly interested in hosting such a facility, it would need to permit SKB to conduct those investigations.

This widely distributed invitation to express an interest evoked little response: only two municipalities in the north—Malå and Storuman—came forward in public. This lack of response prompted SKB to nudge the five nuclear communities—Nyköping, Oskarshamn, Östhammar, Varberg, and Kävlinge—with a survey study. The last two municipalities never pursued the matter, but, subsequently, three nuclear neighbors—Älvkarleby, Hultsfred, and Tierp—joined the remaining nuclear communities and entered the siting process. (See Figure 9 on page 37.)

In a way that it never did previously, SKB came to understand that the success of its siting efforts hinged decisively on voluntarism and local acceptance. The old technocratic organizational culture was ill-matched for the environment in which SKB would now have to operate. New leaders were put in place; individuals were rewarded when they formed bonds of trust with local residents; and, as appropriate, officials maintained a strong presence in the municipalities to answer questions and to reinforce the idea that SKB was not necessarily an outsider.

The eight municipalities that got involved adopted distinctive strategies for making decisions and interacting with SKB.[198] Nyköping's stance, however, set it apart from the others. It believed that conducting feasibility studies was the sole responsibility of SKB. Thus, the municipality maintained mostly a hands-off attitude throughout the process. The seven other communities, however, differed in how they organized themselves to learn about nuclear waste management. Six of them formed steering committees composed of local officials to coordinate local activities. All seven created a reference group, which was mainly responsible for gathering, interpreting, and communicating information from a variety of sources. Local officials, and in some cases, representatives from nongovernmental organizations, were members of these bodies. Advocacy groups sometimes played a central role in some of the municipalities' deliberations, but, in other cases, were completely absent. Except for Storuman, all the municipalities received funding from the central government and were able to secure independent technical advice.

The first two municipalities to express an interest in hosting feasibility—Malå and Storuman—held referenda on whether to allow more extensive site investigations. In the former, further participation in the siting process was rejected by 54 percent of those voting; in the latter, the figure was 71 percent. Once those results came in, SKB immediately left the municipalities.[199] In the six other communities, the decision to approve site investigations was left to the municipal council.

Two municipalities, Nyköping and Tierp, decided not to continue. For technical reasons, SKB eliminated Älvkarleby. Table 8 below summarizes the state of play in each municipality at the end of 2008.

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[198] This discussion and the table that follows it draw heavily on Sundqvist 2002:186:204 as well as Sunqvist, personal communication.

[199] It has been widely observed that SKB's withdrawal probably helped significantly in its future relationship with the municipalities that remained in the siting process.

	Älvkarleby	Hultsfred	Malå	Nyköping	Oskarshamn	Östhammar	Storuman	Tierp
Invitation for involvement	Nuclear neighbor	Nuclear neighbor	Letter to 286 municipalities	Nuclear community	Nuclear community	Nuclear community	Letter to 286 municipalities	Nuclear neighbor
Approved feasibility study	Yes	Yes	Yes	Abstained	Yes	Yes	Yes	Yes
Approved site investigations	SKB decided not to undertake	Yes	No	No	Yes	Yes	No	No
Steering Committee and Reference Group established	Yes	Yes	Yes	RG only	Yes	Yes	Yes	Yes
NGO on SC or RG	Yes—on RG	No	Yes—on RG	Yes—on RG, although left in protest	Yes—on RG	No	No	Yes—on RG
General public on SC or RG	No	No	No	No	No	No	No	No
Organized NGO in support	No	No	Yes—just prior to the referendum	No	No	No	Yes—two different groups	No
Organized NGO in opposition	No	No	Yes	Yes	No	Yes—but late in the process and weak	Yes	Yes
Government financial support	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Independent technical review	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
Referendum	No	No	Yes	No	No	No	Yes	No

SC=Steering Committee RG=Reference Group NGO=Nongovernmental Organization

Table 8. Responses of Swedish communities to SKB's site studies

Although Hultsfred remained in the process, it was never a prime contender, if only because it is landlocked, thereby imposing an extra step on SKB's nautical system for transporting SNF. As a practical matter, then, the choice came down to the two nuclear communities, Östhammar and Oskarshamn.

The two municipalities approached their interactions with SKB in almost opposite ways.[200] Östhammar's engagement with the implementer was low-key. The community organized committees and task forces. It obtained information, not only from SKB, but also from the regulator and the technical overseer. In the end, it believed it had obtained a full range of input, which was carefully analyzed and evaluated.

Oskarshamn's interactions with SKB, both during the feasibility study and the site-investigation phase, were highly visible and well publicized. All the members of the municipal council served on the Reference Group, which oversaw the municipality's engagement with the implementer. Working Groups were formed to conduct studies and analyses. The municipality conditioned its future involvement on clarification of the veto right, revision of the environmental impact assessment process, and the provision of adequate resources to support the "building of local competence." What came to be known as the "Oskarshamn model" for public interaction with the implementer evolved. When completed, it contained seven features:

- Openness and participation: everything is on the table.
- The environmental impact assessment process is integrated into the decision-making process.
- The council is responsible to the voters.
- The public is a resource.
- Environmental groups are resources.
- Stretching SKB: "We build competence so we can ask difficult questions, and we ask until we get clear answers."
- The regulatory authorities are our experts.

Despite the differing styles of engagement, the two municipalities ended up on the same page. Although the time for exercising their veto power lay in the future when the government would have to decide whether to authorize construction of the repository, both communities appeared quite comfortable with the prospect of hosting such a facility. As Figure 20 on page 78 seems to suggest, even when SKB selected Forsmark over Laxemar, the integrity of the process made the outcome acceptable.[201]

United Kingdom

In the United Kingdom, Government created an independent Committee on Radioactive Waste Management (CoRWM) in November 2003. CoRWM's charter was to review the options for the long-term management of HLW and SNF. It was then to recommend an approach that was scientifically and technically sound and that could inspire public confi-

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[200] The difference was a carryover from how the two municipalities behaved during the feasibility phase of the process.

[201] The municipalities did not view themselves as rivals. Apparently without SKB's knowledge, they negotiated with each other a "value-added" agreement. The agreement called for SKB to pay nearly the equivalent of $250,000,000 over 15 years to support local projects, such as education, development of tourism, and improvements to the transportation infrastructure. The "loser" received three-quarters of the money. Although SKB accepted the agreement, it put in place procedures to determine how the value-added money would be spent.

dence. In July 2006, CoRWM delivered its advice. Among its recommendations were five that defined the characteristics and properties of the Social Acceptability Filter (CoRWM 2006:12):

- There should be continuing public and stakeholder engagement, which is essential to build trust and confidence in the proposed long-term management approach, including siting of facilities.
- Community involvement in any proposals for the siting of long-term radioactive waste facilities should be based on the principle of volunteerism, that is, an expressed willingness to participate.
- Community involvement should be achieved through the development of a partnership approach, based on an open and equal relationship between potential host communities and those responsible for implementation.
- Communities should have the right to withdraw from this process up to a predefined point.
- In order to ensure the legitimacy of the process, key decisions should be ratified by the appropriate democratically elected local body/bodies.

In June 2008, the Government published a *White Paper*, in which it adopted these recommendations with slight modifications (DEFRA 2008b). Some ambiguity remained, however, about how the MRWS policy would be implemented on the ground.

In the following months, three local authorities—the Allerdale Borough Council, the Copeland Borough Council, and the Cumbria County Council—expressed interest in hosting a deep-mined, geology repository. The two boroughs are located in the western part of the county. They surround the Sellafield Nuclear Site, which houses, among other things, research reactors, stored radioactive waste, and two reprocessing plants.

By March 2009, the councils authorized the formation of the West Cumbria MRWS Partnership, an association that brought together the three local authorities that had expressed interest, 12 nongovernmental organizations, and four other local authorities. The Department of Energy and Climate Change (DECC) and its subordinate unit and presumptive implementer, the Nuclear Decommissioning Authority, participated as observers, as did several other governmental bodies. The role of the partnership was to develop local competence about radioactive waste management, provide a forum for engaging with DECC, and prepare a report summarizing what was learned and what issues needed to be considered by the local authorities (West Cumbria MRWS Partnership 2012). The county and borough councils that expressed an initial interest would then determine whether to remain involved in the siting process. If they did, desk-based scientific and engineering studies would begin.

By all accounts, the partnership carried out its responsibilities effectively. It gathered and digested considerable information, conducted an extensive engagement and communications program, and placed on its website over 300 records, many of which it authored. The quality of the partnership's work is manifested in its carefully nuanced and reflective final report. In it, the partnership provided wide-ranging advice to the three decision-making councils. The group did not, however, make any recommendation about whether they should proceed to the next stage of the MRWS process.

The partnership did discuss three critical issues where opinion remained divided:

- Were there *specific* suitable sites in West Cumbria where a repository could be constructed?
- Could Government be counted on to respect a decision to withdraw from the process once it gathered momentum and absorbed an ever-increasing amount of resources?
- What commitments would Government give in terms of a community benefits package?

As a previous section of this report notes, the British Geological Survey confirmed in 2010 that, based on the broad and general Exclusion Criteria DECC had specified, potentially suitable sites for a repository could be found in West Cumbria; somewhere in the 1,890 square kilometers of land not ruled out, the Survey maintained, was real estate where a disposal facility might be developed. Just where, it did not say. The partnership concurred with this assessment but requested and received comments on whether a *specific* location could be identified.

The responses from experts were divided (West Cumbria MRWS Partnership 2012:227). Some contended that "West Cumbria's geology is unsuitable and further progress [was] not worthwhile." Others held that "further progress [was] worthwhile because not enough is known to be able to say that all of West Cumbria should be ruled out." Thus, the partnership took no position on whether this issue needed to be resolved either *before* entering into the next stage or *afterwards*. It did observe, however, that most members believed that the question could be settled later on.

The 2008 *White Paper* established as Government *policy* a right of withdrawal up until when "construction is due to start." This right was not codified in law. The partnership pursued this matter and received a letter from DECC's Minister of State.

> I am happy to make a commitment to see this objective [placing the right on a firmer basis] delivered such that, by the end of Stage 4 [desk-based studies] of the MRWS process, Government will have decided what mechanisms it will use to put subsequent aspects of the MRWS process (such as the Right of Withdrawal, planning, inventory change control, and reaching agreements on community benefits) on a clear, transparent and more certain path, and to have started the steps to put these in place. These mechanisms should be legally binding. … The choice of mechanisms should be reached via close engagement with any Community Siting Partnership [that might be established in the future].[202]

This commitment seemingly satisfied the MRWS Partnership. In its final report, however, the partnership never characterized this assurance as ironclad and, at least implicitly, recognized that it might not persuade those who are concerned about it being honored once the process moved beyond the stage of drilling expensive boreholes.

In that same letter, the partnership received a set of 13 "Principles for Community Benefit," including:

- Any benefits must deliver both short- and long-term community well-being.
- Benefits must be *additional* to existing and planned investments, rather than replacing them.

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[202] Letter from Charles Hendry, DECC Minister of State, to Elaine Woodburn, Chair of the West Cumbria MRWS Partnership, July 12, 2012.

- Agreements on community benefits will need to endure over a substantial period of time because of the multigenerational nature of the proposed development.
- In order to establish and maintain community confidence, any agreement on a community benefits package must provide a guarantee that any agreed benefits will be delivered if a site is developed.

The partnership granted in its advice to the local councils that the principles were principles but that the devil was indeed in the details.

> We cannot be certain what specific packages the Government might agree to this far in advance and, therefore, whether the amount and types of benefits would match the expectations of local people. We also recognize that there is widespread skepticism that future governments would follow-through with the agreements (West Cumbria MRWS Partnership 2012:233).

The vote by the local councils was originally anticipated to be held in October 2012, four months after the partnership released its final report. That schedule was not met, in part to allow time for Government to reply to a partnership letter requesting clarification on a number of issues. DECC provided this response in mid-December 2012:[203]

- *With respect to the suitability of the geology:* DECC stated that CoRWM would be asked to scrutinize whether the Nuclear Decommissioning Authority has put in place a viable approach for identifying suitable sites.
- *With respect to the right of withdrawal:* DECC strengthened somewhat its earlier commitments. It promised to consult with the local councils and, within 18 months of a decision to proceed, to reach agreement on the scope of legislation to make the right binding. It detailed a variety of scenarios about what might transpire if technical disagreements arose between the implementer and the local authorities. Although ultimately the *MRWS process* could be stopped, DECC did not retract the statement in the *White Paper* that "if voluntarism and partnership does not look likely to work, Government reserves the right to explore other approaches" (DEFRA 2008b:470).
- *With respect to benefits:* DECC committed, following discussions with the local councils, to make specific funding proposals within 18 months of a decision to proceed.

DECC addressed two other issues in the letter. First, whose vote "counted?"[204] DECC made it clear that "there needs to be three 'green lights' reflecting consent at the three levels of Borough Council, County Council, and national Government. Absent three green lights, the MRWS process cannot continue in West Cumbria." As a practical matter, then, the Cumbria County Council was given veto power. Second, the partnership's final report paid close attention to possible stigmatization special effects and called for measures to protect the "brand." This concern arose chiefly because the Lake District, located in eastern Cumbria, is an area of natural beauty and thus a major tourist destination. DECC promised to support a brand protection program and a national advertising campaign to publicize the Cumbria Lake District brand.

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[203] Letter from Baroness Verma of Leicester, DECC Parliamentary Under Secretary of State, to Alan Smith, Leader, Allerdale Borough Council, December 19, 2012. Identical letters were sent to the leaders of the Copeland Borough and Cumbria County councils.

[204] This question was not anticipated in the *White Paper.*

On January 30, 2013, the Allerdale and Copeland Borough Councils voted 5-2 and 6-1, respectively, to continue with the MRWS siting process. The Cumbria County Council voted 7-3 to withdraw. Although hope was expressed by the borough councils in West Cumbria that somehow the process could be revived, a definitive end to it came the next day with a written statement to Parliament by the Secretary of State for Energy and Climate Change, Edward Davey. He also promised that Government would consider the lessons learned from the West Cumbria experience.

To obtain the lessons learned, DECC issued a "Call for Evidence" in May 2013 to gain the views of interested and affected parties on the site-selection aspects of the MRWS program. Ninety-nine responses were received. In DECC's view, among the key lessons to be learned were the following (DECC 2013:19):

- Need for earlier information on geology that would permit site screening prior to volunteering
- Lack of clarity on the scale, nature, and timing of community benefits
- Lack of clarity on the nature and timing of the right of withdrawal
- Need to create new independent bodies to either peer review the process or make decisions
- Lack of trust in the MRWS process and DECC
- Lack of clarity about the decision-making process

Four months later, DECC launched a formal consultation, presenting its views on how the MRWS process should be restructured. It also solicited public comments on a set of nine questions specifically tied to the changes it was considering (DECC 2013). More than 500 individuals and nearly 200 public and governmental bodies and private organizations presented their opinions (DECC 2014a). In July 2014, DECC published its response to the consultation as well as a *White Paper* laying out Government's new approach to siting (DECC 2014b; DECC 2014c).

The policy revisions announced in the 2014 *White Paper* are substantial.[205] Two overarching differences between the old and the new *White Papers* suggest an important shift in tone and perspective. Whereas the title of the 2008 document directs the readers' attention to "Managing Radioactive Waste Safely," the title of the 2014 document focuses on "Implementing Geological Disposal." Whereas "partnership" between the communities and the implementer was central to the first policy, the concept is not mentioned at all in the description of the second.

More specifically, the *White Paper* envisions a two-year hiatus during which three activities would be pursued. First, the site-selection strategy using Exclusion Criteria would be abandoned (DECC 2014c:32, 35). As noted above, with assistance from the British Geological Survey, the implementer would produce guidance for screening geological environments across England, Wales, and Northern Ireland. The guidance would be subject to a public consultation and an independent review by a reconstituted CoRWM and the well-regarded Geological Society. Once finalized, the implementer would apply the guidance,

[205] Significant differences as well can be found between the positions proposed in the consultation document (DECC 2013) and those contained in the *White Paper* (DECC 2014c). Most notably, in the face of substantial opposition, DECC backed off from its bid to eliminate the county council veto. It also made important modifications to the screening process, specification of community benefits, and governance of the new site-selection process.

again subject to independent review. The outcome of this exercise is designed to inform discussions with potential host communities.[206]

Second, the construction of repository (and the associated boreholes needed to investigate sites) would be designated as a "Nationally Significant Infrastructure Project." This change in status would bring those activities under the Planning Act of 2008. As a consequence, local planning permission, which had governed the development of a repository, would be eliminated. The Planning Act just requires local consultation and the preparation of several impact assessments.[207]

Third, the implementer would begin preparing to work with communities. Broad engagement would take place, directed mainly toward explaining the "science and engineering of geological disposal and associated issues, within the context of Government policy, to the general public" and answering questions raised by the localities (DECC 2014c:42). In addition, "ground rules" governing how the implementer interacts with potential host communities would be finalized. These policies would be determined through the deliberations of a "community representation working group," which would be chaired by DECC and would have a core membership including the implementer, local governments, academics, and other national government organizations.

Once this two-year pause came to an end, the siting process itself would commence. One important feature of the MRWS process remains: voluntarism. But other components have been modified. Instead of a staged process that establishes fixed milestones when a community must affirmatively decide to proceed, a continuous process is established. The right of withdrawal would be maintained throughout the process. But instead of preserving the right up until underground construction was about to start, a community would lose the right once a "test of public support" is conducted and comes out positive. Community benefits would be paid upfront: the equivalent of $1.5 million per year for each community that participates during the early stages of the process and the equivalent of nearly $4 million to communities that progress to the stage when boreholes would have to be drilled. Importantly, one other provision was carried over from MRWS *White Paper*: Government retains the option to explore other, possibly *involuntary* approaches, if necessary (DECC 2014c:31).

But if a new framework was advanced, specification of many of its details would be deferred. A Community Representation Working Group will have to grapple with, among other things, these contentious issues (DECC 2014c:43):

- Defining what is meant by a "community"
- Defining roles and responsibilities of community representatives
- Developing options for ensuring that all levels of local government have a voice in the siting process
- Specifying when it would be appropriate to apply the "test of public support" and the methods for carrying out the test
- Developing options for managing the community benefits package

Perhaps none of these tasks is more demanding than deciding which body can exercise the right of withdrawal. The *White Paper* argues that no one level of government can block the

[206] Draft guidance was issued in September 2015.

[207] Legislation making this change passed Parliament in April 2015.

participation of another, but beyond that, the document is silent on the question of who will have the final say.[208]

Japan

In Japan, in December 2002, NUMO initiated an "open solicitation" by sending an elaborate information package to all of the 3,239 municipalities in the country. The one-page application form to be submitted by communities interested in volunteering for suitability studies based initially on the available literature asked only three questions: a brief description of the potential site; contact points; and "other special information." Upon acceptance by the implementer, any volunteer community would receive the equivalent of $1.7 million.

Nine communities initially expressed some interest in exploring the possibility of hosting a repository. All but one lost their early enthusiasm. Perhaps it was the national government's decision to increase five-fold the payment for agreeing to literature studies that prompted the mayor of Toyo Town on the southeastern coast to step forward.

In January 2007, he gave the completed application to the head of the Ministry of Economy, Trade, and Industry (METI), the cabinet-level organization to which NUMO reported. This action triggered a massive counter-reaction of opposition. That same day the Governor of the Kochi Prefecture, within which Toyo Town lies, announced that he was heading to Tokyo to express his disapproval. "I feel a strong sense of doubt. Something is awry with Japan's nuclear energy policy if procedural work is allowed to begin after the acceptance of the application even though local agreement has not been obtained."[209]

Within a month, 60 percent of the residents in Toyo Town had signed a petition against the study. The Kochi Prefectural Assembly unanimously passed a resolution expressing its displeasure, citing its residents' "anxiety" and a concern about how rumors could affect the Kochi's agricultural, fishing, and tourist industries. Although one neighboring prefecture, Ehime, expressed cautious support for the studies, another, Tokushima, passed a unanimous resolution in opposition, citing the same reasons as did Kochi.

In Toyo Town, citizens circulated petitions to recall the mayor; he soon resigned. The April 2007 election to pick his successor turned on the question of whether NUMO should undertake desktop technical evaluations. The old mayor was defeated by a 2-1 majority, and the new mayor withdrew the application two weeks later.

NUMO's reaction to the lack of response from Japanese communities was first to tinker with its voluntarist approach by enhancing so-called public acceptance activities; improving research and development cooperation; and reinforcing exchanges among the government, implementer, and utility companies. NUMO also broadened its approach by hinting that it might *invite* municipalities to accept desktop studies.

Those modifications proved ineffectual, prompting calls for more fundamental adjustments to the siting process.[210] The first public indication that changes were in the wind

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[208] In July 2015, DECC issued a "Call for Evidence," requesting from interested and affected parties "information on processes for working with communities in the siting of a Geologic Disposal Facility." The evidence would be used by the Community Representation Working Group to develop proposals for addressing these contentious issues (DECC 2015:3).

[209] Reported in Japanese Atomic Industrial Forum, "NUMO Accepts Toyo Town's Application to Become Final Radwaste Disposal Site," *Atoms in Japan*, January 26, 2007.

[210] See, for example, Zhang et al. 2010. The authors, staff members of the National Institute of Advanced Industrial Science and Technology, explicitly recognize the importance of social psychological factors in selecting potential sites for a deep-mined, geologic repository.

came in September 2010, when the Japanese Atomic Energy Commission (JAEC), which provides policy guidance for the country's nuclear activities, asked the Science Council of Japan (the equivalent of the NAS) to examine the country's strategy for the long-term management of HLW and SNF and to suggest improvements.

Six months later, the Great East Japan Earthquake-Tsunami Disaster destroyed the Fukushima Dai-ichi reactors and catalyzed a debate on the broader question of what role nuclear energy would play in Japan's future. The *Reply from the Science Council of Japan to the Japanese Atomic Energy Agency*, therefore, must be viewed both as being influenced by and influencing that discussion.[211]

The council's advice was considered radical because it held that "the reason the policy framework was at a dead-end was not because the explanation to the public was inadequate but that the problem was rooted at a more fundamental level." It questioned whether the technical basis supporting deep-mined, geologic disposal was as mature as its advocates maintained. In particular, given the ubiquitous volcanic and seismic activity on the Japanese Islands, "there is a limit to what we can do with currently available scientific knowledge and technological capacities to search out geological formations that will remain stable for tens of millennium." Thus the *Reply* recommended proceeding with interim storage for tens, if not hundreds, of years.

Further, the council maintained that NUMO's waste-management strategy put the "cart before the horse," seeking consensus on the selection of the location of a final repository for HLW before building a social consensus on general energy and nuclear power policies. Without control over the volume of waste produced, the situation would be akin to "building a mansion without lavatories" and would reinforce public perceptions about things nuclear. Finally, the *Reply* called for the development of policies that mandate "fair burden-sharing" and genuine dialogue.

The JAEC's response to the *Reply*, which came days after a nuclear-skeptical Prime Minister was succeeded by a nuclear-supportive one, foreshadowed the path that would become official the following year. In December 2013, METI's chief announced that "the government will play an active role in choosing a permanent place. We will abandon the current system of waiting for volunteers to raise their hands."[212] In June 2014, the government dismissed NUMO's head because of the implementer's failure to make faster progress. It is unclear, however, how quickly the government will finalize the details of its new approach and, more importantly, when it will publish a list of potential sites.

Table 9 on the next page summarizes the key characteristics of the seven consent-based processes just considered. 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 site will pass through the Social Acceptability Filter.

Creating consent-based siting processes does not offer any guarantee that a site will pass through the Social Acceptability Filter.

211 No English translation of the Reply is available. It is summarized in *Japan for Sustainability Newsletter 124*, December 2012. A JAEC Statement, "Renewing Approaches to Geological Disposal of High-Level Waste," December 18, 2012, also describes the *Reply's* main recommendations.

212 Quoted in *Japan News*, "Japan Takes Nuclear Storage Hunt into Its Own Hands," December 17, 2013.

	Who Consents?	To What Is Consent Given?	How Is Consent Given?	Positive Standard Effects	Negative Special Effects	Outcome
Canada	Local governments and Aboriginal people	Preliminary assessment of geology and community well-being	Expression of interest to NWMO	Varies	Varies	Nine communities out of the initial 22 remain involved.
United States (WIPP)	City of Carlsbad, Eddy County, State of New Mexico	Siting a repository	Invitation/ negotiated withdrawal of public land	High	Low	Repository constructed and operated in Eddy County outside of Carlsbad, New Mexico.
Finland	Municipality of Eurajoki	Siting a repository	Acceptance of the Decision-in-Principle	High	Low	Decision-in-Principle adopted in 2001 selecting the Olkiluoto site near Eurajoki.
France	Communities in the Meuse/ Haute-Marne region	Construction of a URL	Informal negotiations/ nonbinding referenda	High	Low	Transposition zone in Meuse/Haute-Marne near Bure designated in 2006 legislation.
Sweden	Municipality of Östhammar	Feasibility studies and site investigations	Municipal Council vote	Moderate	Low	SKB selected the Forsmark site near Östhammar in 2009.
United Kingdom	Cumbria County, Allerdale and Copeland Borough Councils	Desk-based studies	Agreement from all three councils	Unclear	High in the county but low in the boroughs	Cumbria County Council decided to withdraw from the MRWS process; new approach adopted in 2014.
Japan	Local governments	Desk-based studies	Expression of interest to METI	Unclear	High	No one volunteered; new process announced in 2013.

Table 9. Characteristics of consent-based siting processes

Withholding Consent but to No Avail

United States

By the summer of 1986, the signs were unmistakable that the waste-management program in the United States was in deep trouble. The effort to identify a site for a second repository (Second Round) had just been terminated. The fallout from that decision continued as legislators from the west accused DOE of disregarding the NWPA's promise of geographic equity. The cost of characterizing the sites in Nevada, Texas, and Washington was exploding with no clear limit in sight even as those states vowed to maintain their opposition without end. DOE's proposal to build a centralized interim storage facility in Tennessee was sharply attacked by state leaders.

In the halls of Congress, key members struggled to figure out what to do next. But no easy consensus could be found. Representative Mo Udall of Arizona, for instance, supported a pause coupled with a study by a presidentially appointed commission. As he put it on the floor of the House, "We created a principled process for finding the safest, most sensible place to bury these dangerous wastes. Today, just five years later, this great program is in ruins. Potential host states no longer trust the technical integrity of the Department of Energy's siting decisions" (cited in BRC 2012:135). Another influential legislator, Senator J. Bennett Johnston of Louisiana, believed that DOE should switch its emphasis from disposal to long-term storage of SNF at a centralized site.

Many bills were introduced; hearings were held on a few. But agreement between the House and the Senate proved elusive. In December 1987, Johnston used a conference committee deliberating on a budget reconciliation bill to pave the way for the adoption of the Nuclear Waste Policy Amendments Act. That legislative action, in effect a Social Acceptability Filter, eliminated both the Texas and Washington sites from further consideration; site-characterization work in those two locations had to be shut down immediately. As two commentators put it: "The *raison d'etre* of the [law] was the selection of Nevada" (Colglazier and Langum 1988:350).

The state immediately branded the legislation as the "Screw Nevada Bill." Yet this episode in law-making was no different than most others. Powerful and committed legislators have a disproportionate influence. More specifically, the Vice President and the Speaker of the House hailed from Texas, and the House Majority Leader represented a district in Washington. Nevada's congressional delegation was small and politically weak. Given that constellation of political forces, the outcome was hardly a surprise.[213]

But the passage of the 1987 legislation did fundamentally reorder the country's waste-management policy. The Social Acceptability Filter would henceforth be applied first and the Technical Suitability Filter second. How to pass through that latter hurdle occupied DOE for the next 15 years.

The Nuclear Waste Policy Amendments Act left the NWPA untouched in two important respects. First, DOE would have to demonstrate that Yucca Mountain was technically suitable before it could recommend to the President that it be selected as the site for developing a repository. Second, Nevada retained its right to veto the President's site recommendation. However, a majority vote in both the House of Representatives and the Senate could override that disapproval.

213 Congress' decision was facilitated by the MUA ranking Yucca Mountain in "first place." It is noteworthy that, a quarter-century after the passage of the 1987 legislation, no serious political and historical analysis has been carried out about how that law came to be enacted.

Just how to mesh a suitability determination with the 1987 law was an ongoing topic of conversation within DOE and among interested and affected parties. Although the NWPA required that the *Siting Guidelines* be used, it also permitted DOE to revise them "from time to time, consistent with the provisions of this subsection."[214] In somewhat of a quandary about how to proceed, DOE held a large public meeting in Las Vegas in May 1994, where this issue was one of the topics of discussion. Secretary of Energy Hazel O'Leary and OCRWM Director Daniel Dreyfus actively participated.

In a *Federal Register* notice released in August 1994, DOE announced that it would make suitability decisions using the *Siting Guidelines* as it was currently written. Recognizing the implications of the 1987 legislation, DOE decided that some of the provisions in the regulation were no longer applicable:

> Because the Amendments Act eliminated all of the pre-characterization stages by requiring the Secretary to proceed with site characterization at Yucca Mountain and to cease investigation of all other potential sites for the first repository, comparative evaluation is no longer relevant. Accordingly, the Program will not utilize the comparative portions of the guidelines for purposes of the suitability assessment of the Yucca Mountain site. This means that the Program will not make specific evaluations of the favorable and potentially adverse conditions since these tests are primarily for use in comparing sites.[215]

To implement this strategy, DOE stated that it would prepare a series of "technical basis reports" that would lay the foundations for judging whether Yucca Mountain complied with the remaining criteria set forth in the *Siting Guidelines*. DOE asked the BRWM to review those evaluations.

The first document produced by DOE addressed issues associated with surface characteristics, preclosure hydrology, and erosion.[216] The report's scope was chosen because DOE believed that those topics were not too complex technically and thus were likely to be relatively uncontroversial. Although the report did not draw any regulatory conclusions, its underlying, albeit implicit, message was that Yucca Mountain complied with these requirements in the *Siting Guidelines*.

The BRWM review committee was not asked to consider compliance with the *Siting Guidelines* but only to evaluate the soundness of the report's technical arguments. In this regard it sharply criticized DOE's analyses (NAS 1995a:93-106):

- The scientific and technical questions to be addressed by the report were not clearly stated.
- The report failed to explicitly address all available data in the scientific and technical analyses.

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214 NWPA Section112(a)

215 "Process for Evaluating the Suitability of the Yucca Mountain Site For Development as a Repository for High-Level Radioactive Waste and Spent Nuclear Fuel," *Federal Register*, 59:39,766, August 4, 1994. More than a year later, DOE provided an explanation for its decision. "Use of the 10CFR960 Guidelines in Evaluating the Suitability of the Yucca Mountain Site," *Federal Register*, 60:47,737-47,741, September 14, 1995.

216 Department of Energy, *Technical Basis Report for Surface Characteristics, Preclosure Hydrology, and Erosion*, YMP/TBR-001, Rev. 0, 1995. Those topics address the preclosure technical guidelines 10CFR960.5-2-8 and 960.5-2-10 and the postclosure guideline 10CFR960.4-2-5.

- The report did an inadequate job of compiling and synthesizing available data and analyses.
- The report was prepared using an approach that raised three concerns:
  - There was little room for formulating or testing alternative hypotheses of processes and applying multiple methodologies.
  - There was little opportunity to assess the "hidden" uncertainties that exist because all processes are not measured.
  - The spatial and temporal variabilities in rates and processes were obscured through the use of average values.

The review shook DOE. What was expected to be an easy argument to articulate, even under tight deadlines, only generated what most people regarded as a stinging rebuke.

As DOE pondered what to do next, the events following the passage of the 1992 Energy Policy Act took on new significance. That law instructed EPA and NRC to prepare Yucca Mountain-specific regulations to replace their generic ones.[217] At the same time, the law asked the NAS to suggest a technical foundation for those new rules. In a 1995 report, the committee chartered by the NAS endorsed the use of performance assessment carried out, within the limits imposed by the long-term stability of the geologic environment, until the time of peak dose (NAS 1995b). In the case of Yucca Mountain, that period was roughly one million years. If performance assessment was an appropriate methodology for licensing a repository, then surely, in the minds of DOE officials, it would be equally appropriate and logical to use that technique to determine whether the Yucca Mountain site was suitable.

In December 1996, DOE proposed just that.[218] It concluded that suitability could be determined only in relation to the projected performance of a repository. Discrete, independent findings on individual technical factors would not be required. For example, DOE observed: "A geologic structural feature that provides a fast pathway for groundwater flow may seem a detriment when considered alone but, when considered in conjunction with a specific repository design, may act beneficially by channeling flow away from the waste." Thus, DOE intended simply to add as a new and sole qualifying condition for Yucca Mountain: "The geologic repository shall allow for the containment and isolation of radioactive waste after permanent closure in accordance with the EPA standards established specifically for Yucca Mountain and the NRC regulations implementing those standards." DOE's rationale for this change was not only the expected transformation of EPA and NRC's rules but the "understanding gained" from characterizing the Yucca Mountain site.[219]

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217 At EPA, 40CFR197 replaced 40CFR191, and at NRC, 10CFR93 replaced 10CFR60.

218 "10 CFR Part 960: General Guidelines for the Recommendation of Site for Nuclear Waste Repositories; Proposed Rule and Public Hearing." *Federal Register*, 61:66,158-166,169, December 16, 1996. In that document, DOE asserted that the switch from evaluating individual criteria to carrying out a performance assessment was sanctioned by Congress in a 1996 appropriations conference report.

219 Other than the regulators' responsibility to comment on and perhaps to concur with the implementer's choice of site-suitability criteria, this report does not examine in any great detail the role they play in the site-selection process. The regulator's most important task is to approve or disapprove a license to construct a repository. This report takes as a given, not something to be explained, the rules and standards the regulator uses to discharge that duty. This tack probably underappreciates, especially in the United States, the impact of the regulator on the implementer's siting choices.

DOE's proposal drew strong reactions from interested and affected parties. A number of commenters argued that DOE was changing its rules to fit the site. In their view, Yucca Mountain would be disqualified under the *Siting Guidelines*, especially the one placing a limit on groundwater travel time. A number of responses, including one from the NWTRB, raised concerns about how DOE would conduct its performance assessments.[220]

There matters stood while EPA and NRC were crafting their own proposals to develop Yucca Mountain-specific standards and regulations. In November 1999, DOE issued a revised proposal for amending its site-selection regulation. Partly in response to comments received three years earlier, the implementer significantly expanded its explanation of the approach it sought to codify. Moreover, instead of adding on a short new subpart to its *Siting Guidelines* concerning the use of performance assessment to determine site suitability, it proposed to create an *entirely new* Yucca Mountain-specific rule.[221] The regulation delineated specific requirements that had to be met as DOE carried out its performance assessments.

But if the form and some of the substance of the proposal changed, its core remained the same. With respect to the complaint about changing its rules to fit the site, DOE simply repeated the argument that it made in *Nevada v. Watkins*: it "had not determined whether the groundwater travel time along any pathway of likely and significant radionuclide travel was less than 1,000 years." Therefore, in DOE's mind, it was unclear whether the switch was a game changer. DOE neither abandoned its preference for using performance assessment, nor did it accept feedback from a number of parties about how to overcome some of the inherent limitations associated with that methodology. In particular, comments from the NWTRB about defining in advance both a confidence level and a margin of safety were rejected.[222] That advice, if adopted, likely would have reduced the implementer's discretion.

In May 2000, DOE forwarded its draft final version of its new site-suitability regulation to NRC seeking concurrence as required under the NWPA. NRC staff raised three issues, including the need to address potential conflicts between DOE's siting rule and NRC's Yucca Mountain-specific licensing regulations; DOE's failure to expressly accept NRC's unconditional requirement to conduct a rigorous quality assurance program; and an objection to DOE's assertion that the SNF cladding was corrosion resistant. Unlike in its concurrence process for the 1984 *Siting Guidelines*, NRC decided that it would not hold a public meeting because it believed that it had sufficient information about the views of

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[220] Letter from Jared Cohon, Chairman of the Nuclear Waste Technical Review Board, to April Gil, Department of Energy, April 15, 1997. The Board recognized some practical limitations in applying the *Siting Guidelines* and indicated that the proposed change was a "step in the right direction." However, the Board cautioned DOE that its performance assessment must be carried out in a way that preserves the principle of defense-in-depth, that demonstrates compliance robustly, and that is highly transparent.

[221] "Office of Civilian Radioactive Waste Management; General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories; Yucca Mountain Site Suitability Guidelines," *Federal Register*, 64:67,054-67,089, November 30, 1999.

[222] The NWTRB commented on the proposed revised rule in a March 20, 2000, letter from Jared Cohon, Chairman, to Ivan Itkin, Director, Office of Civilian Radioactive Waste Management, Department of Energy. The NWTRB did not withdraw its earlier comments. In this letter, it also emphasized the importance of analyzing and displaying uncertainty estimates in a clear and transparent way. The NWTRB also underscored the importance it attached to DOE developing multiple lines of argument and evidence to supplement the conclusions drawn from performance assessments. Finally, it reiterated its view, expressed in the April 15, 1997 letter, questioning whether "relying solely on performance assessment to demonstrate repository safety will ever be possible."

interested and affected parties. In October 2001, the regulator formally concurred with the new regulation.[223]

The following month, DOE published the final version of its new site-suitability regulation.[224] It rejected, once again, arguments that the approach embodied in regulation was inconsistent with the NWPA. In particular, DOE disagreed with the State of Nevada's view that the NWPA anticipated that a site-suitability determination would focus solely on the geologic characteristics of the site and not reflect contributions made by the engineered barrier system. DOE also noted that it was still assessing the question of groundwater travel time and asserted that "there is no basis at this time to find that conditions, which would disqualify the site if the [*Siting Guidelines*] were applied, exist at Yucca Mountain." DOE devoted considerable attention to addressing the comments made by the NWTRB. In the Preamble of the *Federal Register* notice issued when it finalized the new regulation, DOE expressed agreement with "much of" the technical overseer's recommendations for carrying out performance assessments. DOE identified the constituents of the rule where many of those suggestions would be addressed. However, it declined to incorporate in the regulation itself specific safety margins and levels of confidence.

On February 14, 2002, DOE Secretary Spencer Abraham forwarded to President George W. Bush a package of information and a recommendation that Yucca Mountain be developed as a deep-mined, geologic repository for HLW and SNF (Abraham 2002). Included in that package was DOE's formal analysis of the suitability of the site (DOE 2002). The key conclusion of that analysis is depicted in Figure 26. According to DOE, the projected performance of the proposed repository would comply with EPA's environmental standard by at least one order of magnitude.[225]

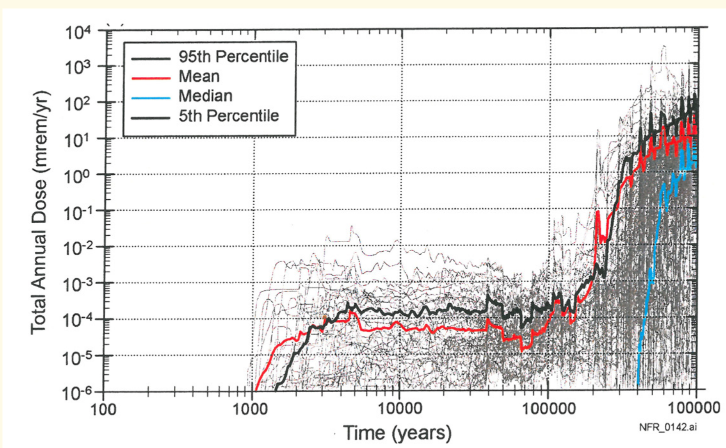

Figure 26. Performance assessment for the site-suitability determination for Yucca Mountain (Source: DOE 2002).

[223] "Final Decision Related to the U.S. Department of Energy's General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories and its Yucca Mountain Site Suitability Guidelines," *Federal Register*, 66:54,303-54,305, October 26, 2001.

[224] "Office of Civilian Radioactive Waste Management; General Guidelines for the Recommendation of Sites of Nuclear Waste Repositories; Yucca Mountain Site Suitability Guidelines," *Federal Register*, 66:57,298-57,340, November 14, 2001.

[225] The EPA environmental standard in place at the time the site recommendation was made set the individual protection dose limit at 15 millirems per year calculated through 10,000 years. The dose limit is based on the mean value of the realizations generated in the performance assessment. Figure 26 shows the nominal scenario. The disruptive scenarios add a small fraction to the amounts shown.

As provided for in the NWPA, Nevada Governor Kenny Guinn on April 8, 2002, filed a Notice of Objection, in effect a veto of the President's decision.[226] A resolution was introduced in both chambers of Congress under special procedures outlined in the NWPA. Hearings were held, and, on July 9, 2002, the Senate joined the House in passing it, thereby overriding Nevada's disapproval and approving the Yucca Mountain site.[227]

Consent-Based Siting: Some Observations

Congressional action in 1987 limited DOE's site-characterization activities to Yucca Mountain. Administrative action since placed the proposed repository in limbo. In 2010, DOE sought to withdraw a license application that it had submitted to NRC 18 months earlier. The effort was rebuffed first by an NRC Atomic Safety and Licensing Board and most recently by the Court of Appeals for the District of Columbia Circuit. It is unclear as of the time this report was written just what the final fate of the proposed Yucca Mountain repository will be.

One ingredient that is framing this ongoing debate, however, is a set of recommendations issued in 2012 by the BRC (BRC 2012). In particular, a centerpiece of the recommendations is that "a new, consent-based approach to siting future nuclear waste-management facilities" be adopted. In its response, the Obama Administration concurred (Chu 2013).

Although the record makes a convincing case that some type of consent-based siting process can lead to the final selection of a repository site, consent by a potential host community may not always be forthcoming. Even before the Great East Japan Earthquake-Tsunami Disaster destroyed the Fukushima Dai-ichi nuclear power plants, 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 and intends to introduce another approach in the near future. The implementer in the United Kingdom experienced virtually the same response when it invited communities to explore the ramifications of hosting a repository. Only the three councils in Cumbria responded positively. One ultimately decided to withdraw, sending the implementer back to square one. A new process has been created, one that still involves some form of voluntarism but eliminates partnership.

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 governments on the other. In Scandinavian societies, allocating strong powers to municipalities is a long-standing

[226] NWPA Sections 115 and 116.

[227] Public Law 107-200, 116 Stat. 735 (2002). The vote in the House was 305-116; the vote in the Senate was 60-39. See Vandenbosch and Vandenbosch 2007:139-172 for a good discussion of the congressional action. The State of Nevada subsequently challenged the site recommendation on both constitutional and statutory grounds. The constitutional challenge was dismissed. The statutory challenge included an attack on DOE's revised siting rule. Regardless of the merits of the state's case, the court ruled that Congress' resolution overriding the state's veto had rendered Nevada's arguments in this area moot. "The Resolution's meaning is clear. … There consequently remains nothing to left to decide. No pronouncement from this court as to the legal soundness of the administrative and executive decisions [can] provide Nevada with any effective relief" (*NEI v. EPA*, 373 F.3rd 1251 (D.C. Cir. 2004, 1311). One important consequence of this court decision was that DOE had to demonstrate compliance with the EPA individual protection dose limit calculated through 1,000,000 years instead of 10,000 years.

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 is unexceptional.

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

In nations whose political structures reflect other traditions, however, figuring out the role of subordinate units (as well as sovereign Native American tribes in the United States) often requires considerable creativity. In France, localities possessed the power to volunteer for an underground research laboratory. But once that power was exercised, decision-making authority transferred to the national Parliament. In the United Kingdom, Government initially required that the county council had to concur. When the Cumbria council declined, the process stopped. The breadth of a county's power has not yet been specified in the newly adopted siting strategy.

This dilemma about how to allocate power between the center and the periphery is especially acute in societies that embrace federalism. In Germany, the standoff between the central and Lower Saxony governments, especially when they were controlled by different parties, has persisted for at least 20 years. A new law, acceptable to all parties as well as the *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 have only a minor role in evaluating the implementer's arguments advanced 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.

The situation in the United States is particularly difficult because of the long-standing legal doctrine of federal preemption. Notwithstanding the special circumstances surrounding the choice of the WIPP site, strong forms of consent-based siting do not find a hospitable environment in the United States. Several examples reinforce this point.

In 1979, the Interagency Review Group on Nuclear Waste Management, which was appointed by President Carter, proposed that a state be asked to "cooperate and *concur*" with the siting of a repository within its boundaries. This formulation was designed to straddle a fine line between "outright federal preemption of any state role in siting a repository and an absolute state veto, exercised at one specific moment in time" (IRG 1979:93-95). Although the IRG tried to distinguish between "consultation and concurrence," and a state veto, it may only have convinced those involved that it was a distinction without a difference. As this report discusses above, during the debate over the WIPP authorization bill that very same year, Representative Price balked at giving New Mexico a decisive say. Further, in the WIPP Land Withdrawal Act, Congress shifted the IRG's formulation to "consultation and *cooperation*." This language was also adopted in the NWPA.

Congress also debated whether it should be able to override a state objection and, if so, how it should accomplish that end. As this report also details above, it settled on majority votes in both houses.[228] As a practical matter, absent extenuating circumstances, most of those participating in writing and lobbying for what eventually became the NWPA acknowledged that the state veto was largely a formality. Congressmen and senators from other states would be reluctant to uphold it, knowing that the search for sites would then have to be restarted.

Although not considered in this report, Congress' disinclination to cede significant power to the states and tribal nations was demonstrated on two other occasions. First, the 1997 Nuclear Waste Policy Amendments Act also created the Office of the Nuclear Waste Negotiator, charged with identifying a volunteer, either for a centralized interim storage system or, less likely, for a repository. Just as the Negotiator was gaining traction in talks with the Mescalaro Apache nation, Congress disbanded the office. Similarly, during President George W. Bush's Administration, Congress enacted legislation and the BLM and the Bureau of Indian Affairs used their administrative authority to construct significant roadblocks to an agreement between several utilities and the Goshute nation to build a centralized storage facility in Utah.

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.

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 did not take 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 were highly regarded by community leaders in Carlsbad, New Mexico.

In rather sharp contrast, it took only a few years for trust to be completely lost between the implementer and officials from the State of Nevada, even though leaders of the county where Yucca Mountain is located remain supportive. If the proposition that "once trust is lost, it is virtually impossible to regain" holds true, Nevada's opposition to a repository at Yucca Mountain could continue unabated.

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

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[228] For a fuller discussion of this debate, see Carter 1997:224-227.

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 bounded by conventional techniques, such as sensitivity and what-if analyses, interested and affected parties may accept a different interpretation than that adopted by 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 a fertile ground for suspicion and opposition.

The BRC did not prescribe in detail what a consent-based process ought to look like, arguing that it is up to the parties themselves to negotiate the modalities and to reach an enforceable agreement. In some respects, that approach is prudent and justifiable. Inventiveness and flexibility is indeed required if the long-standing tradition of federal dominance is to be revised. But, as the Administration's reaction to that advice suggests, it is possible to endorse what appears to be a normatively attractive idea but avoid committing to any specific institutional design.

Yet, the historical record suggests that 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 9.

- 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 9. Elements of successful consent-based siting processes

Interdependence of the Technical Suitability and Social Acceptability Filters

For the purposes of analysis and exposition, this report has up to now considered the Technical Suitability and Social Acceptability Filters largely independently of each other. To be sure, in passing, mention was made about their possible interdependence. In this section, the report focuses on the interconnections that are especially visible in the historical record. The interdependence is illustrated in Figure 27.

In particular, six topics are addressed:

- Simplicity and analyzability of a disposal concept and its social acceptability
- Ordering of the filters
- Technical site-suitability criteria and political influence
- Technical ambiguity, bureaucratic discretion, and social trust
- Nuclear energy production and radioactive waste management
- Technical uncertainty and informed consent

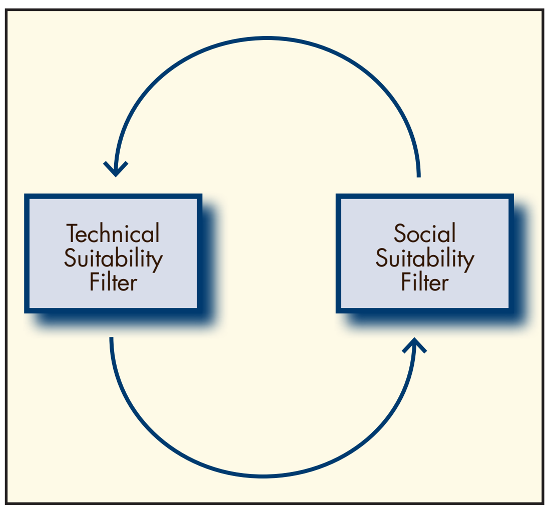

Figure 27. Interdependence of the two filters

Simplicity and Analyzability of a Disposal Concept and Its Social Acceptability

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 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. Further, for most people, 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.

Moreover, the appeal of 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.[229]

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

Ordering the Filters

Notwithstanding the requirement that a site must pass through both Technical Suitability and Social Acceptability Filters, policymakers and implementers have to make a deliberate choice about which filter should be applied first. On the one hand, applying the Technical Suitability Filter at the start runs the risk of expending significant time and resources only to find that the local community then formally or informally blocks passage through the Social Acceptability Filter. On the other, establishing broad and general Exclusion Criteria and putting out a call for volunteers runs the risk that either no locality responds or that the geology of those that do is less than ideal.

For roughly a quarter of a century beginning in the mid-1960s, the implementers in all the countries considered in this report sought initially to pass potential sites through the Technical Suitability Filter. They believed that suitable sites were at a premium. What if a good site could not be found? As a consequence, national waste-management programs single-mindedly focused on identifying those technically attractive locations. Either implicitly or explicitly, they also thought that passage through the Social Acceptability Filter was less demanding and thus could be left to another time. That presumption proved to be unwarranted. Up until the mid-1990s, virtually all the potential sites that were deemed technically appealing failed to pass through the Social Acceptability Filter.

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.

Although the lesson learned from this experience differs somewhat from country to country, in all cases where the siting process bogged down, it was fundamentally restructured to prioritize passage through the Social Acceptability Filter. In France, preliminary techni-

[229] Of course, social acceptability is not the same as compliance with regulatory requirements. To obtain a license for either a simple or complicated repository system located at a particular site, the implementer will have to develop a safety case that relies on complex arguments and logic as well as a performance assessment that demands sophisticated computer modeling.

cal analyses led Bataille to visit eight communities looking for volunteers to host a URL. In Sweden, SKB subordinated the Technical Suitability Filter's role and issued a blanket invitation to all the municipalities in the country. When the response to that solicitation was tepid, it focused its efforts on the nuclear communities and their neighbors, emphasizing all the while that the right of withdrawal would be inviolable. In Canada, Japan, and the United Kingdom, broad and general Exclusion Criteria were established and expressions of interest in hosting a repository were sought.

This shift in strategy has produced mixed results. In France, two *départements* volunteered to host a URL. ANDRA was able to construct a URL along their border, and the site was later selected for the nation's repository for HLW and SNF. No community located near a possibly suitable crystalline rock formation ever volunteered. So to comply with the 1991 Research in Radioactive Waste Management Act, the implementer was forced to compare the Bure site in an argillite formation with a generic site in granite. In Sweden, four out of the eight municipalities that did not object to feasibility studies eventually withdrew from the siting process. In the end, for all practical purposes, only the two nuclear communities remained, communities that SKB, in fact, had targeted for more than 30 years. Much the same pattern emerged in Finland.

In the United Kingdom, the two boroughs in West Cambria volunteered to enter the MRWS process. Although that area passed the broad and general Exclusion Criteria as evaluated by the BGS, it was by no means clear that a specific suitable site could be found. That uncertainty must have been in the minds of the Cambria County councilors when they decided to vote against moving to the next stage of the process. In Japan, a decade ago the mayor of one community did express an interest; but he was soon recalled, and no one else since has been tempted to repeat his mistake. It is noteworthy that both the United Kingdom and Japan have abandoned their initial approach to siting and have concluded that persuasive technical arguments have to be advanced up front. It is still too early in both countries to know what specific process will be adopted.

The siting processes used in two countries, Germany and Switzerland, appear to be anomalous. 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 to take 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.

In sum, what appeared to be a clear shift in ordering the application of the filters—from prioritizing the technical to prioritizing the social—has in the past year reverted back, at least somewhat. For countries in the midst of creating a repository siting process, the implications of this change will need to be assessed.

Technical Site-Suitability Criteria and Political Influences

Crafting indicators of suitability—whether they are Host-Rock-Specific Criteria, Generic Criteria, or broad and general Exclusion Criteria—is a crucial step in most siting processes. As discussed above, implementers are generally resistant to revising draft site-suitability criteria based on input from interested and affected parties. 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.

Although implementers are generally resistant to revise 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 contrast, legislators in the United States and France recognize that the process for selecting a repository site is highly charged and consequential. They firmly believe that it is 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.[230]

In the United States, codifying the *Siting Guidelines* had clear political overtones. These manifested themselves, first of all, in the congressional debate leading to the passage of the NWPA in 1982. Early that year, a House Interior subcommittee considered draft legislation. One of its members, Representative John Seiberling of Ohio, had learned that DOE considered as promising a site in the Cleveland-Akron metropolitan area. He convinced the subcommittee to accept language modifying the siting guideline provision. That amendment would have excluded siting a repository in locations that had even moderately high population density.

Not to be outdone, Congressman Trent Lott of Mississippi sought to have the House Rules Committee include language that prohibited siting of a facility outside any town, regardless of its size. When his colleagues realized that such language would have eliminated virtually all of the sites in DOE's inventory, Lott's amendment was defeated. Another amendment supported by the Mississippi delegation, which would have explicitly eliminated the Richton Dome site from contention, was also rejected. In the end, a more balanced population-density criterion was adopted.

But legislators from the East were not the only ones trying to influence what would be contained in the siting guidelines. Representative David Marriott of Utah succeeded in getting transportation requirements "considered" as part of the site-suitability evaluation. He knew that most reactors were built east of the Mississippi River. As Keith Glaser, a staffer to a legislator from Mississippi remarked: "While we were trying to shove the repository west, they were trying to add all the secret language to shove it east, and they did pretty well at it."[231]

This legislative involvement, it should be noted, was not limited to the passage of the 1982 NWPA. It also can be seen in the 1987 Nuclear Waste Policy Amendments Act. The states' experiences in the Second Round, when DOE identified potential sites near vacation destinations and underneath lakes supplying water to population centers, were not forgotten. A provision dealing with the siting of the second repository instructs the Secretary of Energy to consider seasonal increases in population, proximity to public drinking water supplies, and the impact of site characterization on tribal lands.[232]

Politics of a different sort, bureaucratic politics, surfaced within the DOE group charged with writing the *Siting Guidelines*. NRC had told the implementer that, as a condi-

[230] Sometimes such pressures are visible to all, but often they take place behind the scenes. Consequently, any statement about whether the technical site-suitability criteria were affected by political forces must carry with it a cautionary label.

[231] Quoted in Carter 1987:223.

[232] NWPA Section 161(d).

tion for its concurrence, additional disqualifying conditions needed to be fashioned. With DOE Field Offices and their associated contractors in Nevada, Washington, and Illinois (overseeing the salt sites and the Second Round) championing different potential sites, delicate negotiations within the DOE family ensued over what changes should be submitted to the regulator. At the Chicago Field Office, a manager who was responsible for the two sites in Utah sought to remove language limiting transportation of waste through a national forest. In the Richland Field Office, another project manager expressed concern about a disqualifier having to do with groundwater travel time, which, if accepted as originally written, would have hurt Hanford's chances. At the Nevada Field Office, yet another project manager strongly supported that same language, believing that water moved very slowly in the unsaturated zone at Yucca Mountain.[233]

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. Since then, ANDRA has expended considerable effort developing a strategy that would satisfy the Parliament's site-suitability demand.

Technical Ambiguity, Bureaucratic Discretion, and Social Trust

In any siting process, fairness is a critical imperative, if only because perceptions about the fairness of implementers' decisions strongly influence the social trust they merit.[234] Many considerations influence whether interested and affected parties, especially localities, believe the implementer is behaving fairly, including the transparency of the process, its responsiveness to external feedback, and its adherence to well-defined rules of the game. It is toward the last element that this report now turns.

In principle, the implementer's task in passing a site through the Technical Suitability Filter is simple and straightforward. (1) Develop Technical Suitability Filters. (2) Gather and analyze information about the physical characteristics of the prospective settings or potential sites. (3) Test sites either in parallel or sequentially against the criteria embedded in the Technical Suitability Filters to determine whether any of the locations pass. If more than one does, pick the "best" one. As stated, these activities may appear to be intrinsically objective. In practice, subjective judgments at each stage cannot be avoided, and, by extension, developing universally applicable and fixed rules is simply not possible.

As this report observes in the section on the Technical Suitability Filter, some implementers, such as Posiva Oy in Finland and SKB in Sweden, only advanced very general site-suitability criteria. If that option is foreclosed by law or regulation, the implementers then typically chose to construct Technical Suitability Filters that very often contain squishy benchmarks. This is especially the case if the site-suitability criteria rely on

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233 Memorandum from J. Neff to B. Hewlett, April 16, 1984; Memorandum from S. Whitfield to E.S. Burton, March 14, 1984; and Memorandum from D. Vieth to C. Hanlon and B. Hewlett, March 10, 1984.

234 In virtually all studies examining the factors upon which social trust depends, fairness emerges as an important consideration. See, for example, Poortinga and Pidgeon 2003.

Generic Criteria. Terms, such as "likely," "potentially adverse condition," "sufficient," and "favorable," lie at the heart of such rules that govern the search for a site.

Data gathered in the early stages of site investigations, essentially information from the literature and very preliminary surface-based testing, will, by their very nature, be incomplete and thus often inconclusive. The implementer has the responsibility to evaluate this preliminary data, which can be subject to differing assessments. ANDRA expected that the crystalline rock near Vienne would be less fractured and more analyzable than proved to be the case. At WIPP, the ERDA-6 borehole revealed pockets of pressurized brine that were unexpected based on earlier studies. The Gorleben channel was detected only several years after surface-based testing began. Yet, in each of these instances, the implementer retained interpretive flexibility to determine unilaterally whether the sites in question should be abandoned or work continued.

In some of the cases examined in this report, an implementer's decision to pass a site through the Technical Suitability Filter and to compare one or more nominees went uncontested. Even its strongest advocates at the AEC recognized that the Lyons site could not be rehabilitated. Posiva Oy's final comparison of four candidate sites and SKB's final comparison of two candidate sites was remarkably uncontroversial. In contrast, DOE's winnowing methodology in the Second Round and its use of the MUA to pick three sites to be characterized for the first repository evoked strong complaints about how the implementer exercised its discretion in applying the Generic Criteria laid out in the *Siting Guidelines*. Similarly, dissention about the suitability of the Gorleben site has cast a pall over the German site-selection process for more than two decades.

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

The point here is not that the implementer should not avail itself of the discretion that it legitimately possesses. To advance such a claim would be to ignore the reality of a complex and specialized world: in democratic regimes, bureaucracies are authorized to exercise discretion, in effect to wield power, because of their expertise. Rather, what the historical record reveals is that the implementer's exercise of discretion can allow perceptions of unfairness and bias to form.[235]

For implementers that possess a strong reservoir of trust, exercising discretion is unlikely to be perilous, at least at the start of the siting process. For implementers lacking that reservoir, however, the danger is that the exercise of discretion will only exacerbate the situation, depleting the level of trust at an accelerated rate.

Nuclear Energy Production and Radioactive Waste Management

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

[235] 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.

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. The range of reactions is illustrated below.

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.

In Sweden, the 1977 Nuclear Power Stipulation Act drove the reactor owners to form SKB and to develop the KBS-3 disposal concept. A nonbinding referendum on whether to shut down Sweden's nuclear power plants was held in 1979 following the accident at Three Mile Island in Pennsylvania. Because of the way the options were framed, the outcome was a bit hard to interpret. In the end, Government committed to shutting down all the reactors within 25 years. For a number of reasons, only two plants have been decommissioned so far. But recognizing that nuclear-generated electricity does not produce climate-changing gases, the Swedish Parliament, by an overwhelming majority, lifted the ban on the construction of new nuclear reactors in 2009.[236] As a result of the policy consensus over the past 30 years, 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.[237]

In the United Kingdom, the original CoRWM considered how the prospect of building new reactors might affect the repository siting process.

> CoRWM believes that its recommendations should not be seen as either a red or green light for nuclear new build. The main concern in the present context is that the proposals might be seized upon as providing a green light for new build. That is far from the case. New build wastes would extend the time-scales for implementation, possibly for very long but essentially unknowable future periods. Further, the political and ethical issues raised by the creation of more wastes are quite different from those relating to committed, and therefore, unavoidable wastes. Should a new build program be introduced, in CoRWM's view it would require a quite separate process to test and validate proposals for the management of the wastes arising (CoRWM 2006:12).

When Government rejected this recommendation, four former members wrote the Secretary of State for Energy and Climate Change: "We do not consider it credible to argue that effective arrangements exist or will exist either at a generic or site-specific level for the long-term management of highly radioactive wastes arising from new nuclear build."[238]

The West Cumbria Managing Radioactive Waste Safely Partnership asked Government whether its views about this piece of CoRWM's advice had changed. In response, it reiterated its previous position: "The Government considers that it would be technically possible and desirable to dispose of both new and legacy waste in the same geological disposal

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[236] After the vote, the leader of the Centre Party, which was elected on an anti-nuclear platform and briefly governed in the mid-1970s, was quoted as saying, "I'm doing this for the sake of my children and grandchildren. I can live with the fact that nuclear power will be part of our electricity supply system in the foreseeable future" (*Guardian*, February 2, 2009). Economic considerations may limit how many new reactors will be built in Sweden and may force the closure of at least some of the power plants now operating. Ironically, in September 2015, the majority owner of the three plants has said it would close them because they were uneconomic to operate.

[237] SKB's 2011 submission of a license application for a final repository in Östhammar will be reviewed by the Land and Environmental Court. At least one of the nongovernmental organizations involved in that proceeding is avowedly anti-nuclear and brings that perspective to bear in its critique of KBS-3.

[238] Letter from A. Blowers, G. MacKerron, M. Allan, and P. Wilkinson to Edward Miliband, November 20, 2009.

facilities and that this should be explored through the Managing Radioactive Waste Safely program" (West Cumbria MRWS Partnership 2012:72). In its final report, the partnership took no position on whether the Technical Suitability Filter for a repository whose inventory was limited to legacy waste should be any different from a filter for a repository that held both legacy and new-build waste. It did recommend, however, that that question be the subject of future negotiations between the implementer and the community (West Cumbria MRWS Partnership 2012:226). At the very least, inventory size is likely to be a point of focus as a new siting approach is taken in the United Kingdom.

In Germany, the issue of nuclear power's future most forcefully affected the repository siting process. The broad political consensus in favor of nuclear power began to break down in the mid-1990s, as the Green Party pushed the Social Democrats into taking an antinuclear stance. That shift at both the Federal and *Länder* levels, had profound consequences. Technical discussions at the political level about the suitability of the Gorleben site were colored by partisan positions. As noted in the section on the Social Acceptability Filter, the rationale for suspending site investigations in 2000 was that the studies could not resolve generic questions relating to the salt disposal concept. Additional studies could, however, provide useful information about how those generic questions affected a specific site.

When the Christian Democrats regained control over the Federal Government in 2010, site investigations were almost immediately restarted. Six months later, the Great East Japan Earthquake-Tsunami Disaster destroyed the Fukushima Dai-ichi nuclear power plants. Subsequently, a political consensus formed to phase out nuclear power by 2022. Only then could all parties agree to establish the framework for a new siting process. Yet some individuals and groups opposed to nuclear power production remain skeptical. They have not participated in the new siting process, arguing that once the waste issue is "solved," the phase out will be reversed.

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.

Technical Uncertainty and Informed Consent[239]

In countries that have selected a site for a deep-mined, geologic repository, the timing of both consent(s) and the associated right to withdraw varies. In France, the communities near the Meuse/Haute-Marne boundary volunteered to host a URL with the understanding that a repository might subsequently be developed nearby. In Finland, the Municipality of Eurajoki gave its consent when a "Decision-in-Principle" was taken by Government and the Parliament. That action was based solely on preliminary surface-based investigations. In Sweden, the Municipality of Östhammar must agree to Government granting

[239] What follows is adapted from Metlay and Ewing 2013.

a license to construct the repository. Again, the timing of that act comes after data have been collected only from the surface. In nations that have established consent-based siting processes but have not selected a site, such as Canada and the United Kingdom, communities initially express interest, but they maintain the right to withdraw up to some predetermined point. In Canada, that point of "no-return" is the conclusion of surface-based technical investigations. Under the now-abandoned MRWS process in the United Kingdom, Government stipulated an identical milestone.[240]

In this regard, the United States is very much the exception to prevailing international practice. The State of New Mexico accepted the 1992 Land Withdrawal Act only after the WIPP site had been fully characterized. Under the NWPA, sites must be fully characterized, including studies at depth at the repository horizon, before a state is required to give its approval or disapproval.[241]

The timing of consent(s) and the associated right of withdrawal reflects a *fundamental tension* between the implementer and a potential repository host community. As site characterization progresses from literature reviews to surface-based studies to underground investigations at depth, knowledge accumulates. For a community concerned about the possibility of a surprise during characterization, postponing final consent to as late a stage as possible makes sense. Then it can evaluate how the implementer has resolved outstanding technical questions and uncertainties. At the same time, a community must be sensitive to the possibility that, as characterization proceeds, momentum for the project may build to the point that it is difficult to reverse course and withdraw consent, particularly in the face of accumulating sunk costs. In contrast, the implementer wants final consent to be given as early as possible in the process. It worries about investing significant sums to get underground only to discover that the potential host has decided to object even before the regulatory authority has passed judgment.

How troubling *is* this fundamental tension? No evidence at all can be found in the historical record to suggest that either the communities around Bure or the Eurajoki and Östhammar municipalities now regret offering their consent or that they would wish to withdraw it if given the opportunity.

But as the dynamic in the United Kingdom under the MRWS policy reveals, the fundamental tension can very much be on everyone's minds. The implementer's perspective was clearly laid out in the 2008 *White Paper* (DEFRA 2008b).

> In order to minimize financial risk and uncertainty, *before* the [implementer] embarks on a borehole survey program, the circumstances in which a post-borehole right of withdrawal might be exercised should be identified. …
>
> The requirement to define these circumstances before a borehole program [is launched] is likely to be both challenging and beneficial; challenging because it will involve matters of judgment; and beneficial because the definition will focus discussion, enhance understanding, and make criteria for a right of withdrawal deci-

[240] The 2014 *White Paper* (DECC 2014c), however, took a different tack. A yet-to-be-defined "test of public opinion" would be conducted at some yet-to-be-determined point in time. If a still-to-be-established population responded favorably, then the relevant locality would lose the right of withdrawal.

[241] Of course, as this report observes in the previous section, a state withholding consent can, under current law, have its disapproval overturned.

> sion explicit before extensive work has been undertaken [emphasis added] (DEFRA 2008b:57).

As this report explains in the section on the Social Acceptability Filter, maintaining the right of withdrawal as a viable option was an ongoing concern addressed in the West Cumbria Partnership's final report, a concern that the local councils subsequently pursued with Government.

How troubling *should* this fundamental tension be? Specifying early on the "circumstances" that would justify withdrawal is, as the 2008 *White Paper* observes, "challenging." Put another way, how much more *informed* would consent (or withdrawal) be if it could be deferred, as it is in the United States, until site characterization is complete? The answer to that question hinges on (1) how stable the safety case is that underlies the implementer's chosen disposal concept and (2) the importance of information that can be obtained only by explorations at the repository horizon.

By their very nature, safety cases should resist deep-seated changes. But such shifts are not unknown. The Swedish disposal concept and associated safety case, the KBS-3 method, dates from the mid-1970s. The concept acknowledges that the elemental copper waste canisters could corrode because of sulfide in the groundwater. However, according to the KBS-3 safety case, the canisters would not corrode in an anoxic environment free of sulfide. An additional barrier is the bentonite clay buffer, which retards both the movement of water toward the canister and any radionuclide release away from it. As this report notes in the section on the Technical Suitability Filter, some recent experiments have challenged the corrosion resistance of the canisters in anoxic environments and the effectiveness of the bentonite barriers. Although these studies are by no means definitive, they could lead to significant modifications in the KBS-3 disposal concept.

The argument in favor of the proposed Yucca Mountain repository originally rested upon the belief that water passed slowly from the surface through various layers of volcanic tuff until it reached the level where the waste would be emplaced. Once DOE constructed the Exploratory Studies Facility to gain access to the repository horizon, experiments seemed to suggest that water moved more rapidly than expected through fractures in the rock. This finding led directly to a reassessment of a key parameter of the safety case, percolation flux, and prompted a decision to construct an elaborate engineered barrier system composed of, in DOE's view, corrosion-resistant waste packages and drip shields.

Safety cases differ in terms of their evidentiary support and robustness. Many of these safety cases have been subjected to international peer reviews (NEA 2003, 2004, 2006, 2012; NEA and IAEA 2002). Some of the safety cases, such as those that envision a deep-mined, geologic repository sited in either clay or salt formations, are closely tied to measurable physical properties of the host rock (ONDRAF/NIRAS 2001; Nagra 2002a; ANDRA 2005a, 2005b). In contrast, the safety case for a repository located at Yucca Mountain rested upon claims made about complex interactions between the geologic and engineered barriers that would arise under above-boiling operating conditions (Abraham 2002).

Surface-based investigations start out by evaluating the generic or assumed properties of the host rock, such as the sealing characteristics of plastically deforming salt or the slow movement of groundwater through poorly indurated clays. During this initial stage, most of the geologic data will come from the literature and detailed surface mapping followed by a variety of remote-sensing techniques (e.g., mapping fractures using sensors at different wavelengths) or geophysical surveys (e.g., magnetic and radiometric surveys from the air or land-based seismic profiling).

Later on, a more detailed examination is carried out by drilling rock core samples at depth to obtain site-specific information on the characteristics of the rock. At this stage, the three-dimensional properties of the site begin to emerge. Pump tests between wells can be used to assess the hydrologic properties of the site, and samples of water can be dated to determine the degree of isolation from the near-surface biosphere. The exact placement of the repository horizon may be adjusted during this stage in order to avoid faults, fracture zones, or less desirable rock types.

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.

The final stage of site characterization requires underground workings that may be the first step in the construction of the repository. 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.

In fact, it is only at this last stage that a clear picture of the geology, hydrology, and subsurface processes of the site at the repository horizon can be obtained. As the Chairman of the NWTRB wrote to the Secretary of Energy,

> The Board has long believed that surface-based testing alone will not provide the critical information needed to determine site suitability. … The information gained through a visual inspection and evaluation of the underground geology will be of tremendous value in judging potentially disqualifying conditions, such as ground-water flow and fault movement.[242]

At each of these three stages, substantial changes in the originally envisioned safety case can occur. As evidence accumulates and the safety case evolves, one can imagine that it might cause a local community to withdraw from the project. However, the issue for the local authorities is to know when a "surprise" becomes an appropriate reason for withdrawing consent. Such decisions are very difficult to make, again as the 2008 British *White Paper* acknowledges, because they require projections of performance over hundreds of thousands of years. Any consent-based process has to empower the local community with enough technical expertise that it can arrive at a satisfactory understanding of and confidence in the long-term performance of the repository.

[242] Letter from Donald Deere, Chairman, Nuclear Waste Technical Review Board, to James Watkins, Secretary of Energy, November 7, 1991.

Implicit in the fundamental tension, at least outside of the United States, is the belief that, once surface-based testing has been completed, only minor features of the candidate site remain hidden. It is difficult to know how valid this belief might be, although the experience at Yucca Mountain and at ERDA-6 suggests that it may not be rare. Moreover, one should note that these first two stages of site characterization are typical of other geoscience activities, such as the exploration for mineral and hydrocarbon deposits. 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 geologic exploration is the surprise and that failure must be anticipated and accepted.

In some ideal world, the fundamental tension would not manifest itself. The implementer and the community would interpret new information identically and would reach a common position about the direction of a repository project. In the real world, however, the implementer may not acknowledge that critical issues have emerged. But even if it does, the implementer has an incentive to "fix" problems as they arise, even if that requires modification of the safety case or interpreting ambiguous information in the most favorable way. *Such adjustments can be entirely appropriate; in fact, they are to be expected in any staged and adaptive siting process*. Whether the changes would lead a community to regret the consent it has given at some earlier time, however, remains an open—and an entirely different—question.

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 B\oard 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.

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Acronym List

AEC	Atomic Energy Commission
AECL	Atomic Energy of Canada Limited
AkEnd	Committee on a Selection Procedure for Repository Sites
ANDRA	National Radioactive Waste Management Agency
BfS	Federal Office for Radiation Protection
BGS	British Geological Survey
BLM	Bureau of Land Management
BMU	Ministry of Environment, Nature Conservation, and Nuclear Safety
BMWi	Ministry of the Economics and Technology
Board or NWTRB	Nuclear Waste Technical Review Board
BRC	Blue Ribbon Commission on America's Nuclear Future
BRIUG	Beijing Research Institute for Uranium Geology
BRWM	Board on Radioactive Waste Management
CCA	Compliance Certification Application
CEA	Atomic Energy Commission
CLIs	Local Information and Oversight Committees
CNE	National Commission for Evaluation
CoRWM	Committee on Radioactive Waste Management
COX	Callovo-Oxfordian
CSRR	Candidate Site Recommendation Report

DECC	Department of Energy and Climate Change
DOE	Department of Energy
EEG	Environmental Evaluation Group
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ERDA	U.S. Energy Research and Development Administration
HLW	high level radioactive waste
IAEA	International Atomic Energy Agency
IRG	Interagency Review Group on Nuclear Waste Management
JAEC	Japanese Atomic Energy Commission
KEWA	Nuclear Fuel Reprocessing Company
KGS	Kansas Geological Survey
METI	Ministry of Economics, Trade, and Industry
MRWS	Managing Radioactive Waste Safely
MUA	multiattribute utility analysis
Nagra	National Cooperative for Disposal of Radioactive Waste
NAS	National Academy of Sciences
NEA	Nuclear Energy Agency
NIMBY	not in my backyard
NRC	Nuclear Regulatory Commission
NUMO	Nuclear Waste Management Organization
NWMO	Nuclear Waste Management Organization
NWPA	1982 Nuclear Waste Policy Act
NWTRB	Nuclear Waste Technical Review Board
OCRWM	Office of Civilian Radioactive Waste Management
ONDRAF/NIRAS	National Agency for Radioactive Waste and Enriched Fissile Material
ORNL	Oak Ridge National Laboratory
PTB	Physickalisch-Technische Bundesanstalt
RCRA	Resource Conservation and Recovery Act
RSSF	Retrievable Surface Storage Facility
SKB	Swedish Nuclear Fuel and Waste Management Company
SKI	Nuclear Power Inspectorate

SNF	spent nuclear fuel
STUK	Radiation and Nuclear Safety Authority
URL	underground research laboratory
USGS	U.S. Geologic Survey
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.

assessment, deterministic A simulation of the behavior of a system utilizing a single-valued set of parameters, events, and features. *See* also **assessment, probabilistic.**

assessment, environmental impact An evaluation of radiological and nonradiological impacts of a proposed activity where the performance measure is overall environmental impact, including radiological and other global measures of impact on safety and environment.

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.

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*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).

barriers, multiple Two or more natural or engineered barriers used to isolate radioactive waste in, and prevent radionuclide migration from, a repository. *See* also **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.

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.

defense-in-depth The application of more than one protective measure for a given safety objective so that the objective is achieved even if one of the protective measures fails.

direct disposal Disposal of spent nuclear fuel as waste.

disposal Emplacement of waste in an appropriate facility without the intention of retrieval.

disposal facility Synonymous with "repository."

dose limit The value of the effective dose or the equivalent dose to individuals from releases from a repository that may not be exceeded.

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.**

environmental impact statement A set of documents recording the results of an evaluation of the physical, ecological, cultural, and socioeconomic effects of a proposed facility (e.g., a repository), of a new technology, or of a new program.

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.

geological barrier *See* **barrier.**

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

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.

gneiss A metamorphic rock form characterized by banding caused by segregation of different types of rock, typically light and dark silicates.

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.

heat-generating waste *See* **waste, heat generating.**

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.

intermediate-level waste *See* **waste, low- and intermediate-level.**

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-lived waste *See* **waste, long-lived.**

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

low- and intermediate-level waste *See* **waste, low- and intermediate-level.**

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.

multiple barriers *See* **barriers, multiple.**

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.**

preclosure The period of time spanning the construction and operation of a repository up to and including the closure and 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).

scenario A postulated or assumed set of conditions or events. Scenarios are commonly used in performance assessments to represent possible future conditions or events to be modeled, such as the possible future evolution of a repository and its surroundings.

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.**

spent nuclear fuel management All activities that relate to the handling or storage of spent nuclear fuel.

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.**

surface facility A repository's buildings or transportation infrastructure that are constructed above ground.

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.

vitrified waste *See* **waste glass.**

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

waste, heat-generating Radioactive waste that is sufficiently radioactive that the decay heat significantly increases its temperature and the temperature of its surroundings. In practice, heat-generating waste is normally high-level waste, although some types of intermediate-level waste may qualify as heat-generating waste.

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, intermediate-level *See* **waste, low- and intermediate-level.**

waste, long-lived Radioactive waste that contains significant levels of radionuclides with half-lives above 100 years.

waste, low- and intermediate-level Radioactive waste with radiological characteristics between those of waste exempted from regulation and high-level waste and spent nuclear fuel. They may be long-lived waste or short-lived waste. Many countries subdivide this class in other ways—for example, into low-level waste and intermediate-level waste or medium-level waste, often on the basis of waste acceptance requirements for near-surface repositories.

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, vitrified *See* **waste glass.**

waste disposal *See* **disposal.**

waste form Waste in its physical and chemical forms after treatment.

waste generator The operating organization of a facility or an activity that produces waste.

waste glass The vitreous product that results from incorporating waste into a glass matrix. *See* also **glass.**

APPENDICES

Appendix 1

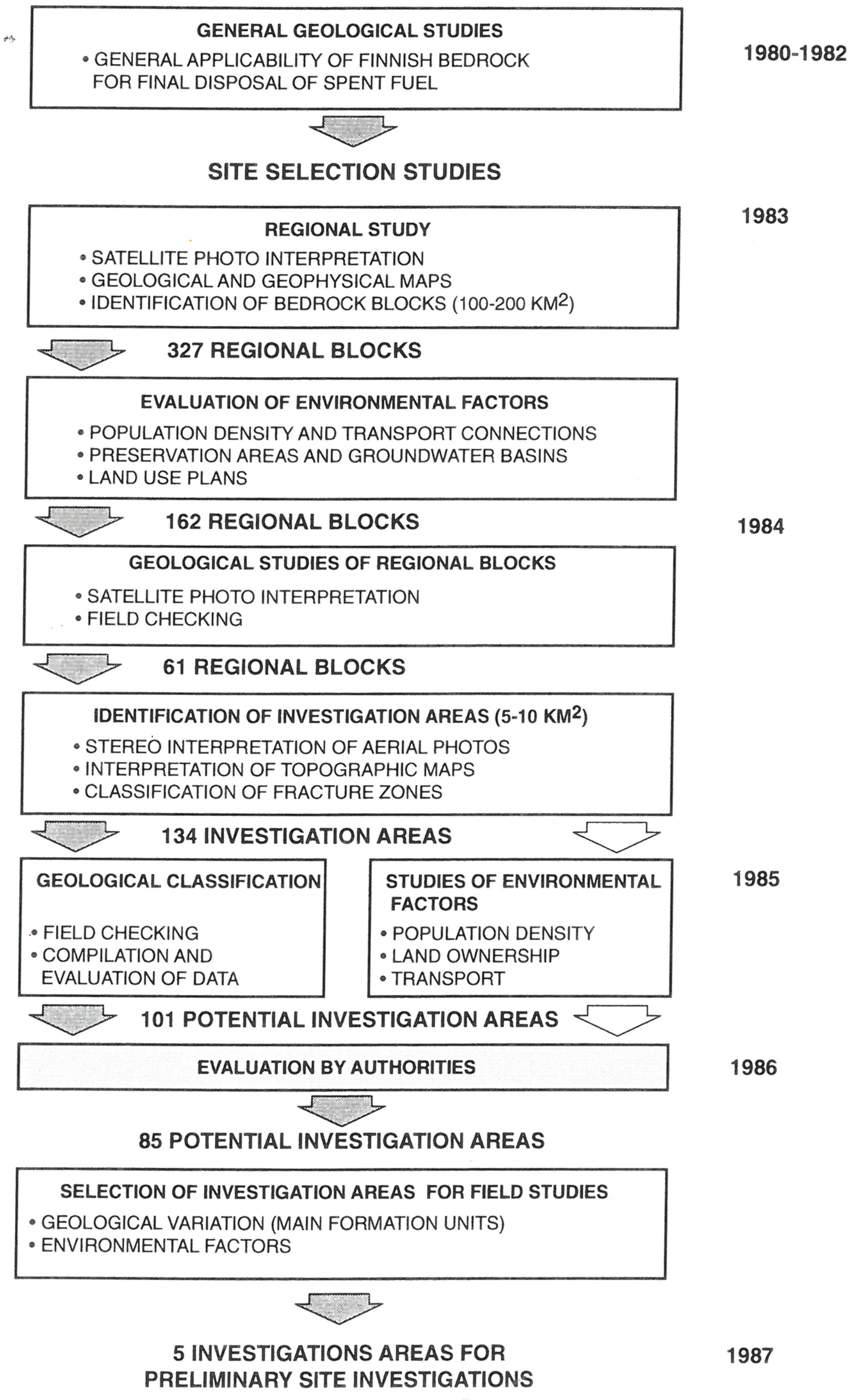
Formal Stages in the Site-Selection Process

Canada

Getting Ready	**The NWMO publishes the finalized siting process, having briefed provincial governments, the Government of Canada, national and provincial Aboriginal organizations, and regulatory agencies on the NWMO's activities.** The NWMO will continue briefings throughout the siting process to ensure new information is made available and requirements which might emerge are addressed.
Step 1	**The NWMO initiates the siting process with a broad program to provide information, answer questions and build awareness among Canadians about the project and siting process.** Awareness-building activities will continue throughout the full duration of the siting process.
Step 2	**Communities identify their interest in learning more, and the NWMO provides detailed briefing. An initial screening is conducted.** At the request of the community, the NWMO will evaluate the potential suitability of the community against a list of initial screening criteria (outlined on page 30).
Step 3	**For interested communities, a preliminary assessment of potential suitability is conducted.** At the request of the community, the NWMO will conduct a feasibility study collaboratively with the community to determine whether a site has the potential to meet the detailed requirements for the project. Interested communities will be encouraged to inform surrounding communities, including potentially affected Aboriginal communities and governments, as early as possible to facilitate their involvement.
Step 4	**For interested communities, potentially affected surrounding communities are engaged if they have not been already, and detailed site evaluations are completed.** In this step, the NWMO will select one or more suitable sites from communities expressing formal interest for regional study and/or detailed multi-year site evaluations. The NWMO will work collaboratively with these communities to engage potentially affected surrounding communities, Aboriginal governments and the provincial government in a study of health, safety, environment, social, economic and cultural effects of the project at a broader regional level (Regional Study), including effects that may be associated with transportation. Involvement will continue throughout the siting process as decisions are made about how the project will be implemented.
Step 5	**Communities with confirmed suitable sites decide whether they are willing to accept the project and propose the terms and conditions on which they would have the project proceed.**
Step 6	**The NWMO and the community with the preferred site enter into a formal agreement to host the project.** The NWMO selects the preferred site, and the NWMO and community ratify a formal agreement.
Step 7	**Regulatory authorities review the safety of the project through an independent, formal and public process and, if all requirements are satisfied, give their approvals to proceed.** The implementation of the deep geological repository will be regulated under the *Nuclear Safety and Control Act* and its associated regulations to protect the health, safety and security of Canadians and the environment, and to respect Canada's international commitments on the peaceful use of nuclear energy. Regulatory requirements will be observed throughout all steps in the siting process. The documentation produced through previous steps, as well as other documentation that will be required, will be formally reviewed by regulatory authorities at this step through an Environmental Assessment and then licensing hearings related to site preparation and construction of facilities associated with the project. Various aspects of transportation of used nuclear fuel will also need to be approved by regulatory authorities.
Step 8	**Construction and operation of an underground demonstration facility proceeds.** The NWMO will develop the centre of expertise, launched in Step 4, to include and support the construction and operation of an underground demonstration facility designed to confirm the characteristics of the site before applying to regulatory authorities for an operating licence. Designed in collaboration with the community, it will become a hub for knowledge-sharing across Canada and internationally.
Step 9	**Construction and operation of the facility.** The NWMO begins construction of the deep geological repository and associated surface facilities. Operation will begin after an operating licence is obtained from regulatory authorities. The NWMO will continue to work in partnership with the host community in order to ensure the commitments to the community are addressed throughout the entire lifetime of the project.

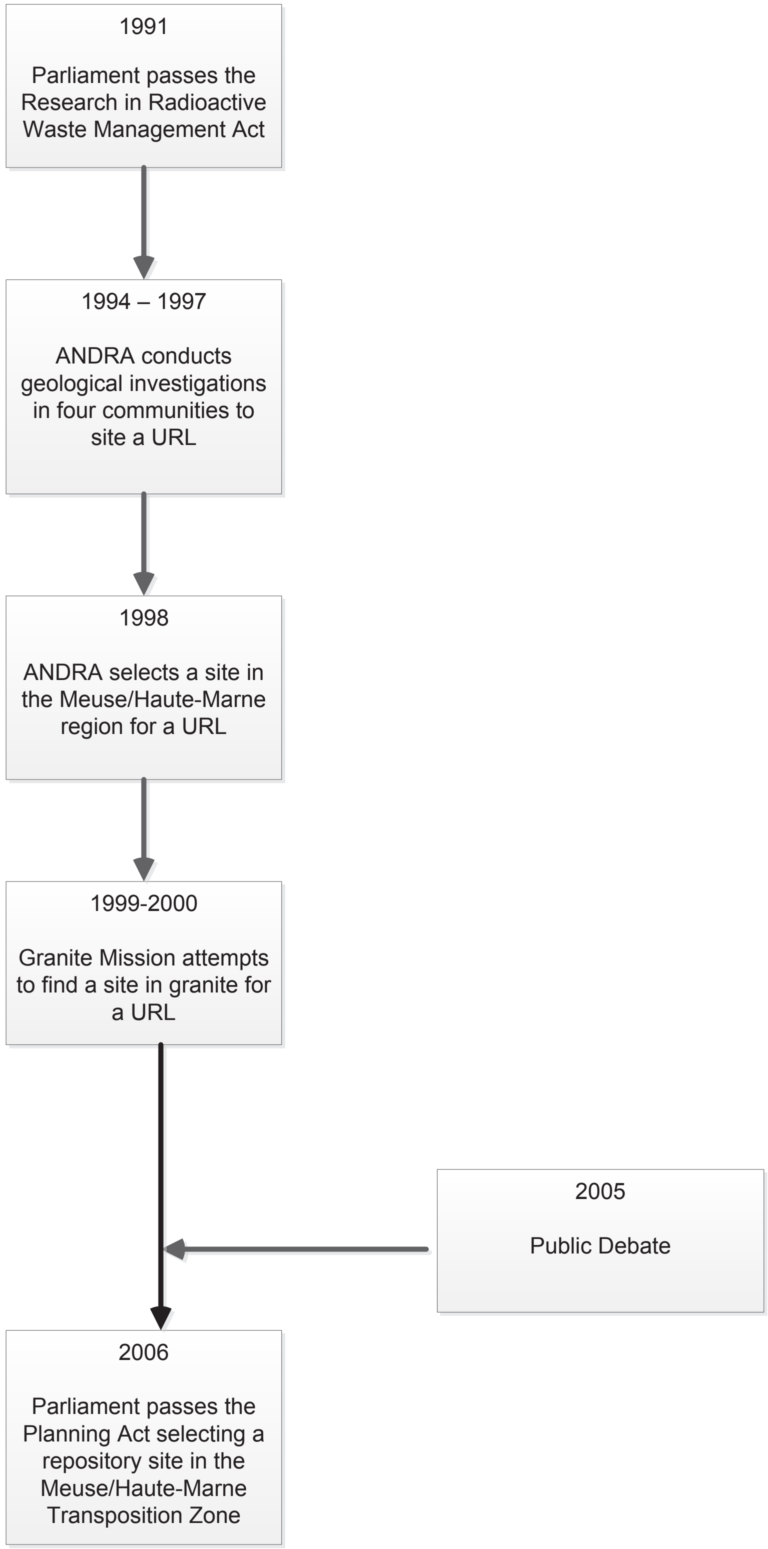
Source: NWMO 2010

Finland



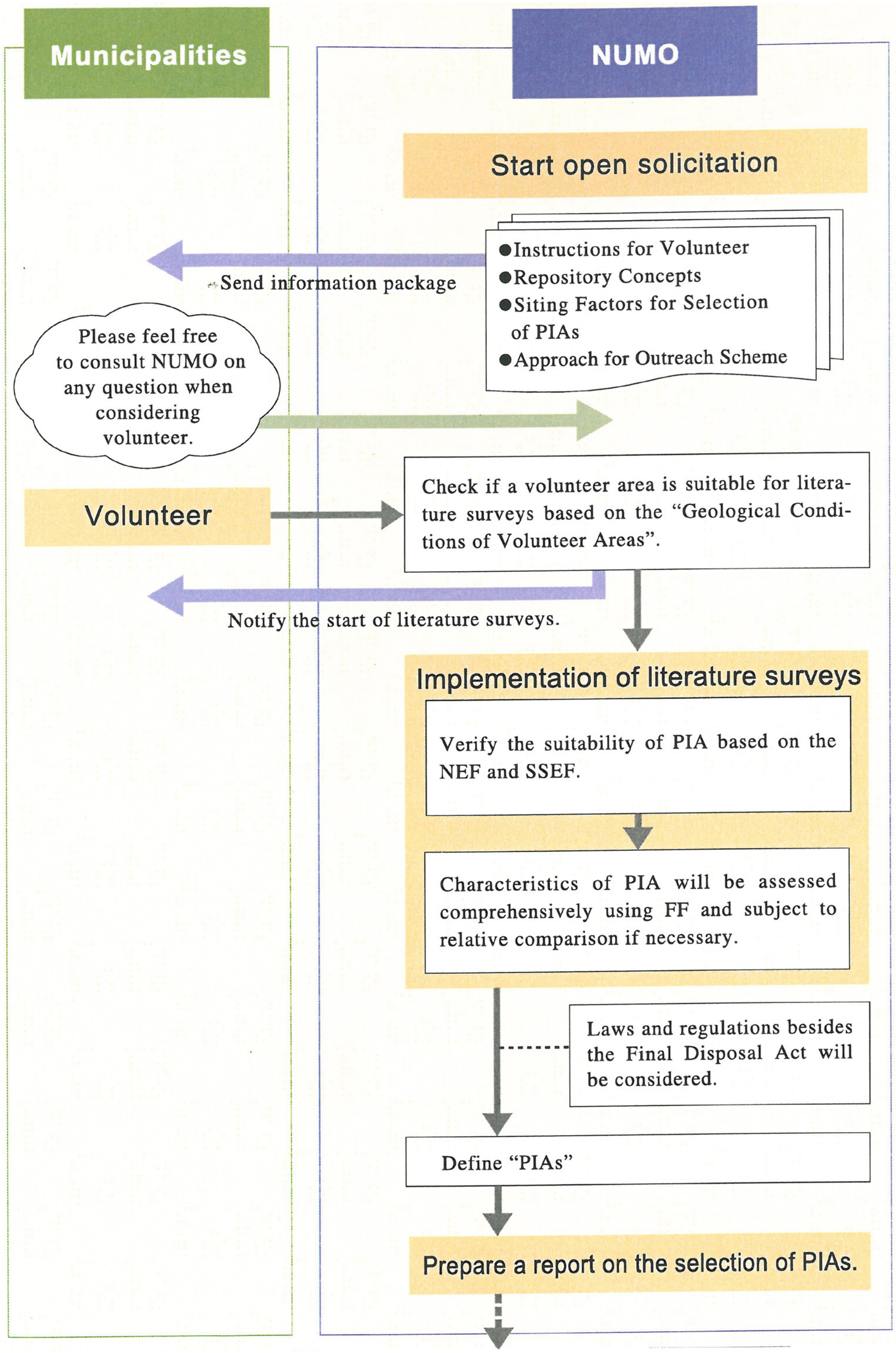
Source: McEwen and Äikäs 2000

France



1991
Parliament passes the Research in Radioactive Waste Management Act
1994 – 1997
ANDRA conducts geological investigations in four communities to site a URL
1998
ANDRA selects a site in the Meuse/Haute-Marne region for a URL
1999-2000
Granite Mission attempts to find a site in granite for a URL
2005
Public Debate
2006
Parliament passes the Planning Act selecting a repository site in the Meuse/Haute-Marne Transposition Zone

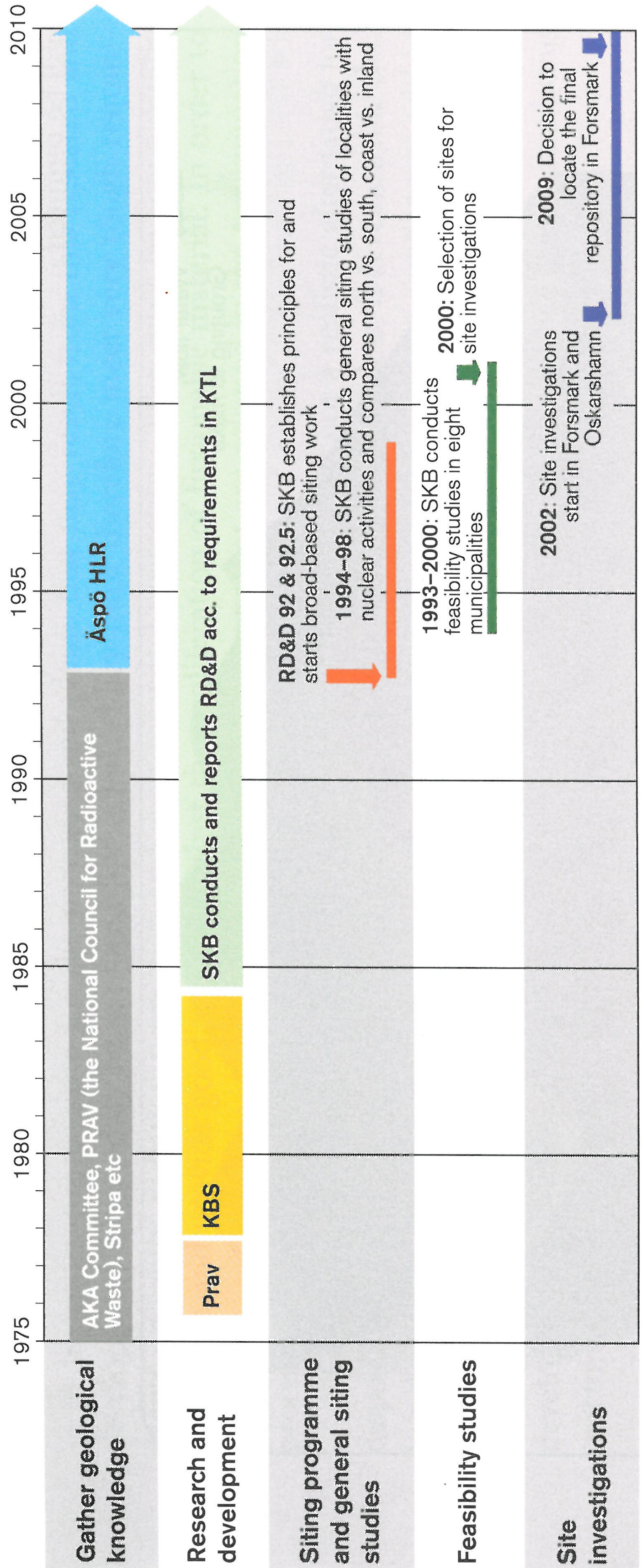
Japan



PIA=Preliminary Investigation Area; NEF=Nationwide Evaluation Factors; SSEF=Site-Specific Evaluation Factors; FF=Favorable Factors

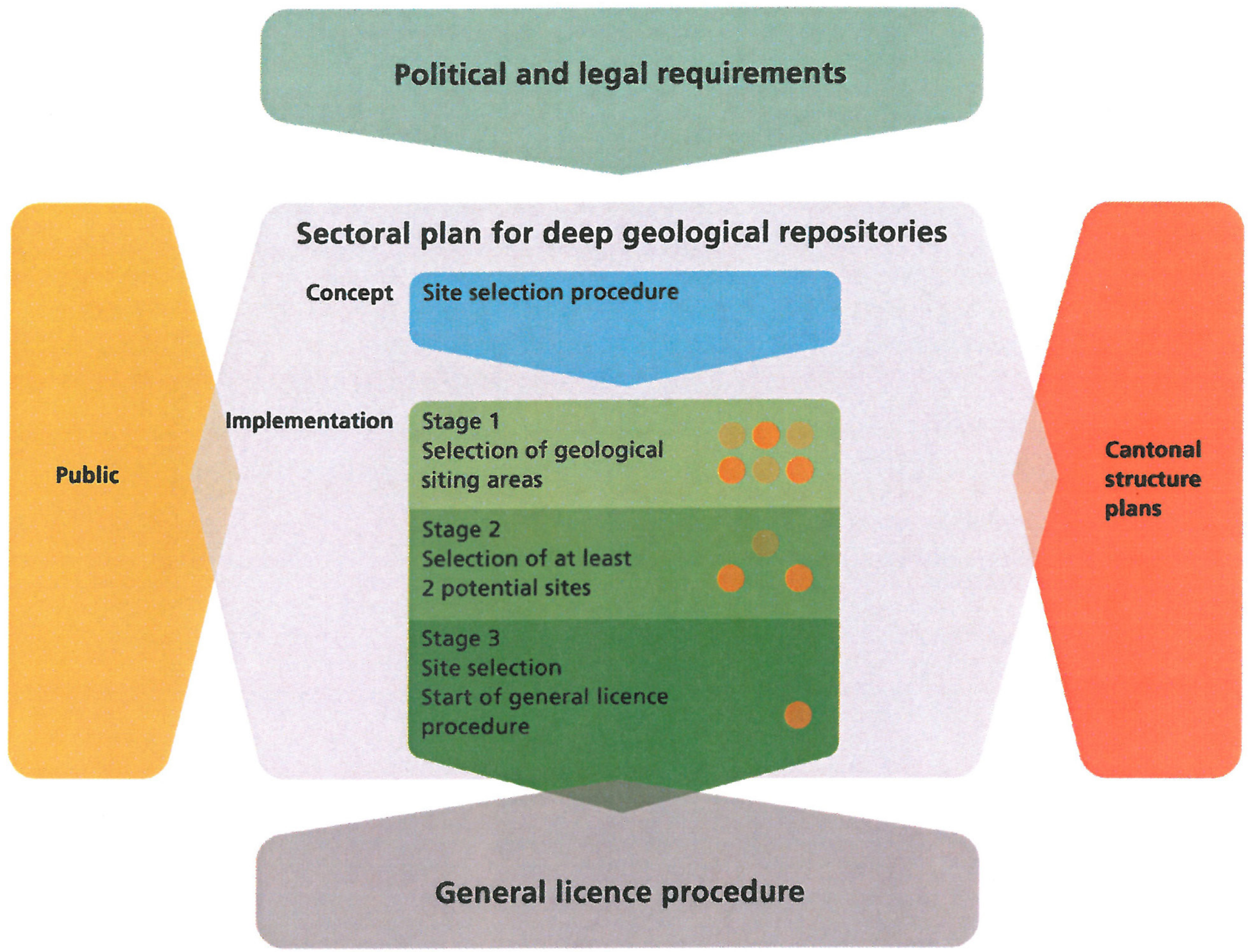
Source: NUMO 2002a

Sweden



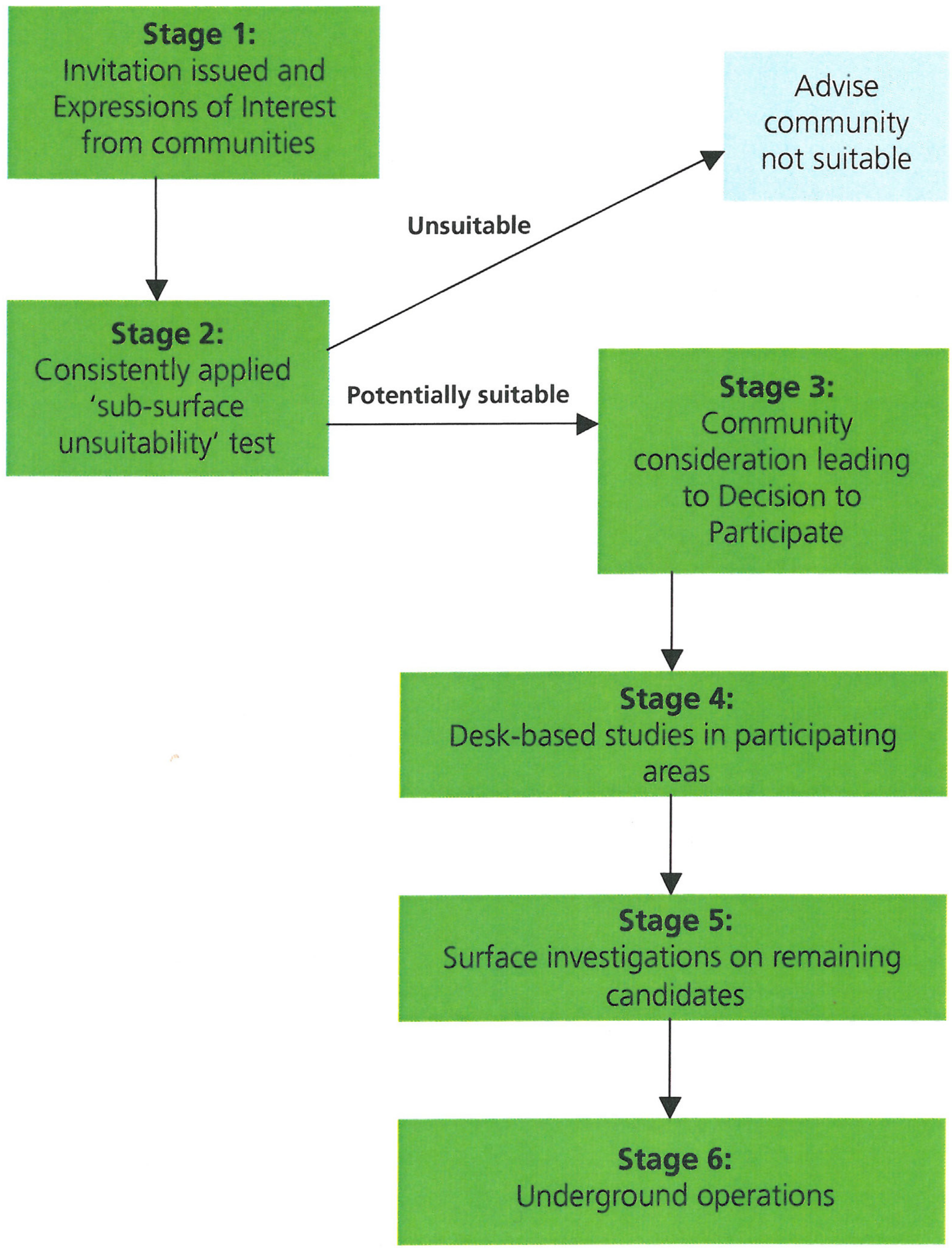
Source: SKB 2011b

Switzerland



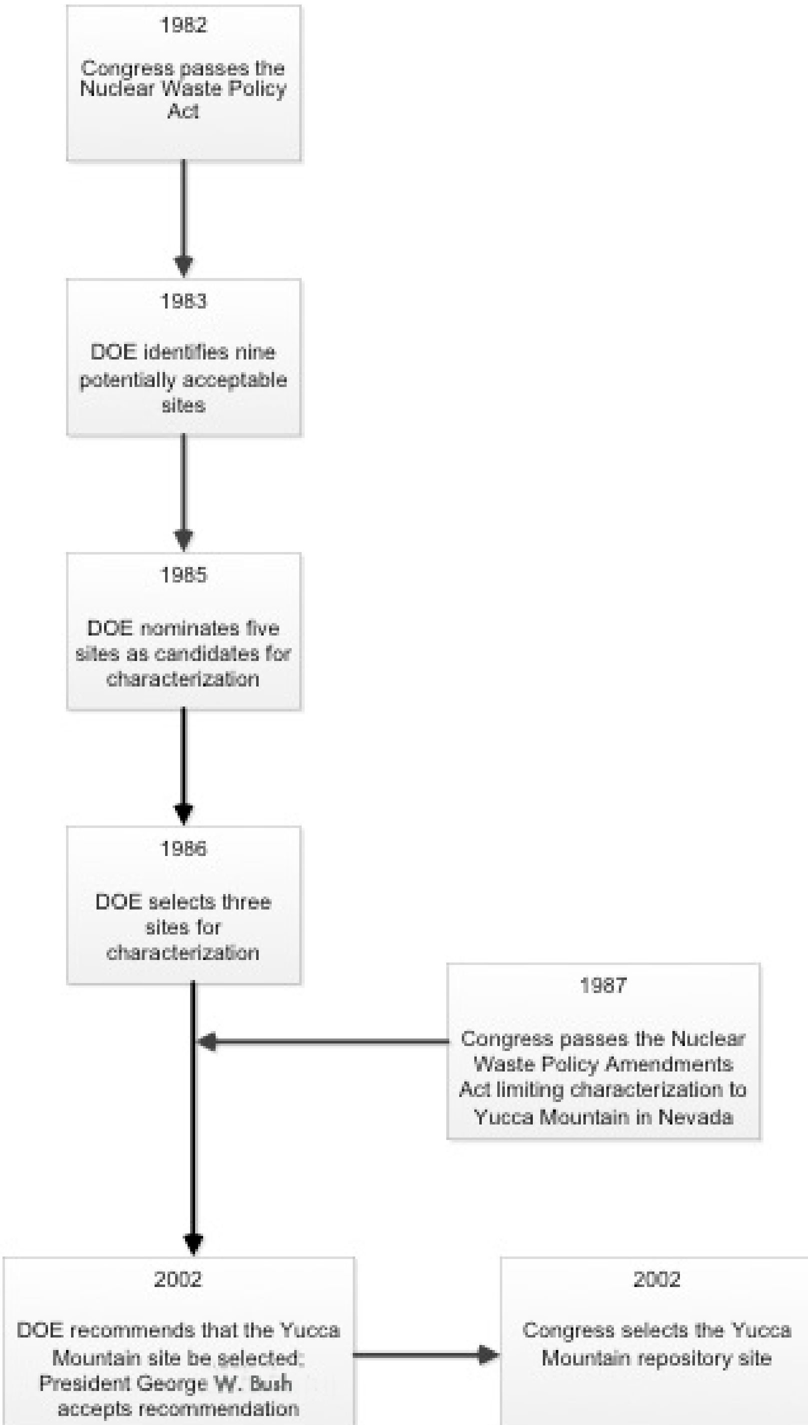
Source: SFOE 2008

United Kingdom



Source: DEFRA 2008b

United States



Appendix 2

Timelines for National Waste-Management Programs

Canada

1969-1976	Atomic Energy Control Board (AECB) instructs Atomic Energy of Canada Limited (AECL) and Ontario Hydro (reactor owner) to investigate geological disposal.
1977	Hare Report recommends disposal in deep-mined, geologic repositories.
1978-1981	AECL conducts repository-siting assessments in Ontario.
1981	Siting assessments are halted. The Federal and Ontario governments agree that a disposal concept must be approved prior to restarting the siting process.
1982-1989	Negotiations take place among the Federal Government, the Ontario Government, and Ontario Hydro regarding the terms of reference of a future public inquiry.
1989	Seaborne Panel is established. Its mandate is limited to evaluating AECL's proposed disposal concept.
1990	Public scoping sessions are held for Seaborne Panel inquiry.
1996-1997	Seaborne Panel holds public hearings in three phases.
1998	Seaborne Panel releases its report holding that AECL's proposed disposal concept lacked public acceptance.
2002	Government passes Nuclear Fuel Waste Act, establishing the utility-owned Nuclear Waste Management Organization (NWMO) as the implementer.
2002-2005	NWMO holds public meetings and consultations.
2005	NWMO recommends Adaptive Phased Management as a strategy for developing a deep-mined, geologic repository.
2007	Federal Government approves Adaptive Phased Management.
2007-present	NWMO invites communities to learn about the implications of hosting a repository; technical screening of 22 sites begins.

Finland

1977-1980	Four nuclear power plants, two at Olkiluoto and two at Loviisa, begin operation.
1977-1996	Spent nuclear fuel (SNF) from the Loviisa reactors is returned first to the Soviet Union and then to Russia.
1980-1982	Teollisuuden Voima Oy (TVO), the owner of the Olkiluoto reactors, begins general geological studies to determine whether the Finnish bedrock could be used for the final disposal of SNF.
1983	Finnish Government determines that disposal in deep-mined, geologic repositories should be the nation's strategy for the long-term disposition of SNF.
1984-1986	TVO screens regional blocks to identify investigation areas and proposes 101 potential areas to the Finnish Government.
1986	The Finnish Government approves 85 investigation areas.
1987	TVO decides to study five investigation areas.
1996	Fortum Power, the owner of the Loviisa reactors, joins TVO to form Posiva Oy. Posiva Oy is responsible for developing the repository.
1997	Hästholmen, the community hosting the Loviisa reactors, is added as a sixth investigation area.
1999	Posiva Oy submits to the Finnish Government an application for a "Decision-in-Principle," requesting the approval of site in the Eurajoki Municipality, where the Olkiluoto reactor is located, for a repository.
2000	The Finnish Government approves the Decision-in-Principle.
2012	Posiva Oy submits an application to construct a deep-mined, geologic repository for SNF to the nuclear regulator, the Radiation and Nuclear Safety Authority, STUK.

France

1978	The French Government decides to reprocess all commercial SNF. The liquid high-level radioactive waste (HLW) is vitrified and stored at the reprocessing plant at La Hague.
1979	The National Agency for Radioactive Waste Management (ANDRA) is created as a department in the Atomic Energy Commission (CEA).
1987-1990	Site investigations begin in four areas, each with a different geological formation. Public protests cause them to halt.
1990	The Parliamentary Office for Scientific and Technological Choices organizes a series of public hearings on radioactive waste management.
1991	The French Parliament passes the Research in Radioactive Waste Management Act. The law makes ANDRA independent of the CEA. It calls for a three-pronged research and development program. The CEA is given responsibility for investigating long-term storage and transmutation. ANDRA becomes the developer of a deep-mined, geologic repository for HLW.
1994-1998	New geological site investigations are started in four communities that have volunteered to possibly host an underground research laboratory (URL).
1998	The area around the community of Bure near the border of the Meuse/Haute Marne *départements* agrees to host a URL to be built in an argillite formation.
2000	Government empanels a group to find a community willing to host a URL to be built in a crystalline rock formation. Local protests prevent the group from achieving its objective.
2002-2005	ANDRA conducts investigations at the URL.
2005-2006	National debate on radioactive waste management takes place.
2006	The French Parliament passes the Radioactive Materials and Waste Planning Act, selecting an area along the Meuse/Haute Marne border as the site for a deep-mined, geologic repository.

Germany

1960s-early 1970s	The German Government selects a disposal concept featuring a repository constructed in salt formations. Initial site-selection activities are conducted but are brought to a halt by public protests.
1973	A private company, KEWA, begins a process to site a nuclear complex, consisting of a reprocessing plant, a fuel fabrication plant, and a deep-mined, geologic repository in the State of Lower Saxony.
1977	The Government of Lower Saxony selects the Gorleben salt dome as a repository site. Plans for the other facilities that were to be a part of the nuclear complex are withdrawn.
1977	The German Government accepts the choice of the Gorleben site.
1979	Hearings are held on the suitability of the Gorleben site.
1979	Site investigations begin at the Gorleben site.
1985	Two shafts are constructed to permit studies underground.
1996	Underground investigations begin.
2000	Federal elections bring to power a coalition composed of the Social Democratic and Green Parties. Government declares a moratorium on further studies at Gorleben.
2002	A Committee on Site Selection Procedure for Repository Sites (AkEnd) proposes comprehensive stepwise process as well as site-suitability criteria to pick sites for a repository from a “white map” of Germany. AkEnd’s proposals are not adopted.
2010	The election of a government led by the Christian Democratic Party lifts the Gorleben moratorium but re-imposes it after the Great East Japan Earthquake-Tsunami Disaster destroyed the Fukushima Dai-ichi nuclear power plants.
2013	The German Parliament passes the Repository Site-Selection Act, which creates a commission to recommend how a new site-selection process should be designed.

Japan

1992-2000	Research organizations develop repository concepts that rely on very robust engineered barrier systems and carries out two formal safety assessments.
2000	Japanese Diet passes the Designated Radioactive Waste Final Disposal Act, which, among other things, defines a procedure for repository site section.
2000	The Nuclear Waste Management Organization (NUMO) assumes responsibility for developing a deep-mined, geologic repository.
2001	NUMO publishes a methodology that relies on three phases to winnow down potentially suitable sites.
2002	NUMO issues an invitation to municipalities to explore the possibility of hosting a deep-mined, geologic repository.
2007	The mayor of Toyo Town submits application to the Ministry of Economy, Trade, and Industry agreeing to desk-based studies to determine whether a site in that community is technically suitable for developing a repository.
2007	The Mayor of Toyo Town resigns. Running in an election to fill his position, he is heavily defeated by a repository opponent.
2013	Japanese Government abandons search for a volunteer community.

Sweden

1977	The Swedish Parliament passes the Nuclear Power Stipulation Act, which requires that reactor owners demonstrate how and where HLW and SNF can be disposed of with "absolute safety."
1977	The utility-owned implementer, Swedish Nuclear Fuel and Waste Management Company (SKB), proposes the KBS-1 disposal concept.
1979	The nuclear regulator, Swedish Nuclear Power Inspectorate, accepts the KBS disposal concept as the blueprint for demonstrating absolute safety.
1980	SKB begins systematic geological investigations to find a site where a repository based on the KBS disposal concept might be developed.
1984	The Swedish Parliament replaces the Nuclear Power Stipulation Act with the Act on Nuclear Activities.
1985	Public demonstrations over test-drillings lead to termination of SKB nationwide geological investigations.
1992	SKB shifts its siting strategy to one based on local acceptance and voluntarism.
1995	SKB invites four established nuclear communities to agree to feasibility studies.
2001	Swedish Government approves site investigations at Östhammar, Oskarshamn, and Tierp.
2009	SKB announces that it has selected a site in the Östhammar Municipality for development of a repository.
2011	SKB submits to the nuclear regulator, the Swedish Radiation Safety Authority, an application to construct a deep-mined, geologic repository in the Östhammar Municipality.

Switzerland

1978	The Federal Government begins searching in crystalline rock for a deep-mined, geologic repository site for high-level radioactive waste (HLW) (Project Gewähr).
1985	The focus of the site-selection process switches to Opalinus clay.
1985	The implementer, Nagra, starts to search for a site for a long-lived low- and intermediate-level waste repository.
1993	Wellenburg, in the Canton of Nidwalden, is identified as one of four potential sites for a long-lived low-level repository.
1995	A cantonal referendum rejects the application for a repository.
2000	The Federal Government establishes an expert group (EKRA) to compare various disposition options.
2002	A cantonal referendum rejects the application for a repository for a second time.
2004	The Federal Government concludes that a site in crystalline rock for a HLW repository cannot be found.
2008	The Federal Government determines that developing a repository in Opalinus clay is feasible. It releases the Sectoral Plan, which structures the siting process.
2012-present	The first stage of the Sectoral Plan is completed when the Federal Government approves Nagra's choice of three siting regions for a deep-mined, repository for HLW and SNF. The second stage of the Sectoral Plan begins.

United Kingdom

1987-1995	The then-implementer, Nirex, begins a search for a site for an intermediate-level waste repository.
1997	Cumbria County Council rejects Nirex's application for planning permission to develop an intermediate-level waste repository near the Sellafield nuclear complex.
1999	House of Lord's Science and Technology Committee releases a report recommending a fresh approach to radioactive waste management, one that focuses on public and stakeholder engagement.
2002	A new implementer, the Nuclear Decommissioning Authority (NDA), is established.
2003	An independent Committee on Radioactive Waste Management (CoRWM) is created to advise Government on a new policy.
2006	CoRWM recommends geological disposal, long-term interim storage, and a partnership/voluntarism approach to siting.
2006	Government accepts CoRWM's recommendations (for the most part) and creates the Managing Radioactive Waste Safely (MRWS) program.
2009	Two Boroughs and the County Councils in Cumbria agree to participate in the MRWS program.
2013	The Cumbria County Council votes to withdraw from the MRWS process.
2014	Government releases a White Paper establishing a new siting process, which still relies on voluntarism but not partnership.

United States

1944	Large volumes of high-level radioactive waste (HLW) are produced for the first time at the Hanford Reservation as part of the Manhattan Project.
1957	A panel of the National Academy of Sciences considers the HLW issue and recommends disposal of liquid HLW in a deep-mined, geologic repository constructed in salt formations.
1963-1972	The Atomic Energy Commission conducts studies in an unused salt mine near Lyons, Kansas. Siting attempts there fail in 1970 and the site is abandoned in 1972.
1977-1979	President Carter forms the Interagency Review Group on Nuclear Waste Management (IRG). In its final report, the IRG recommends state "consultation and concurrence" in siting a repository. It also recommends that multiple sites in different geological formations be investigated before a final selection is made.
1982	Congress passes the Nuclear Waste Policy Act, which endorses the IRG's views about characterizing multiple sites but morphs "consultation and concurrence" into "consultation and cooperation."
1983	The Department of Energy (DOE) identifies nine potentially acceptable sites for the NWPA-mandated first repository and 17 regions for the NWPA-mandated second repository.
1985	DOE finalizes its *Siting Guidelines* and the final methodology for selecting potentially acceptable sites for the second repository.
1986	DOE winnows down to three sites for the first repository and cancels the second repository program.
1987	Congress passes the Nuclear Waste Policy Amendments Act, which limits site-characterization to Yucca Mountain in Nevada.
2002	Congress approves the selection of Yucca Mountain as the site for a deep-mined, geologic repository.
2008	DOE submits a construction license application for the Yucca Mountain repository to the Nuclear Regulatory Commission.
2009-present	The Obama Administration determines that development of a repository at Yucca Mountain is "unworkable."

Appendix 3

Host-Rock-Specific Criteria Used to Identify Potential Sites in Lower Saxony

(BMWi 2008:49-51)

Federal Institute for Soil Research

- Salt formation 400-500m thick
- Homogeneous rock salt
- Large horizontal dimension
- Surface of the salt body 300-800m underground
- Low permeability of overburden
- Good transport infrastructure
- Proximity to planned reactor sites

Nuclear Fuel Reprocessing Company (for back-end nuclear complex)

- Exclusion of nature conservation, recreation, and tourist areas
- Surface area of 6 km^2
- Exclusion of flight corridors, drinking water protection areas, and earthquake zones
- Sparse population
- No significant dairy industry
- Favorable engineering conditions
- Potential for a geologic repository
- Flow rate of nearest river and distance to federal borders and nuclear power plants

Lower Saxony

- Location of the 3x4 km^2 compared to the perimeters of the salt dome
- Size of salt dome (the bigger the better)
- Depth of salt dome less than 800 m
- Low population density
- Competing claims for land use

Appendix 4

Criteria for Selecting Potential Sites in Washington and Nevada, United States

(Lomenick 1996:134, 152)

Washington

The Department of Energy identified five prospective setting in basalt using 23 parameters based on the Nuclear Regulatory Commission's *Draft Repository Criteria*, the Department of Energy's Office of Nuclear Waste Isolation's *Draft Site Qualification Criteria*, and the National Academy's *Siting Guidelines*. Within those settings, ten potential sites were evaluated based on:

- Bedrock fractures and faults
- Lineaments
- Potential earthquake sources
- Groundwater travel times
- Contaminated soil and/or groundwater that is incompatible with surface facilities
- Thickness of the dense interior of the host flow
- Tiering within the host flow
- Natural vegetative communities
- Unique microhabitats
- Special species

Two of the potential sites dominated the others. Since they were almost coincident in area and location, they were combined to form the "Reference Repository Location."

Nevada

The Department of Energy identified four prospective settings in volcanic tuff: Tram and Bullfrog Members of the Crater Flat Tuff, the Tuffaceous Bed of the Calico Hills, and the Topopah Spring Member of the Paintbrush Tuff. (The first two settings were above the water table; the second two were below it.) On the basis of available data, the Topopah Spring Tuff setting was selected as the repository horizon. The Host-Rock-Specific Criteria that were used to compare the settings were:

- Thermal conductivity and expansion
- Rock-mechanical properties of the matrix and fractures
- Bulk properties of the rock
- Overall thermomechanical stratigraphy of the formations

Appendix 5

Post-Closure Site-Suitability Criteria Contained in the United States Siting Guidelines

(10CFR960)

§ 960.4 Postclosure guidelines.

The guidelines in this subpart specify the factors to be considered in evaluating and comparing sites on the basis of expected repository performance after closure. The postclosure guidelines are separated into a system guideline and eight technical guidelines. The system guideline establishes waste containment and isolation requirements that are based on NRC and EPA regulations. These requirements must be met by the repository system, which contains natural barriers and engineered barriers. The engineered barriers will be designed to complement the natural barriers, which provide the primary means for waste isolation.

§ 960.4–1 System guideline.

(a) *Qualifying Condition*. The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure in accordance with the requirements of 40 CFR Part 191, subpart B, as implemented by the provisions of 10 CFR Part 60. The geologic setting at the site will allow for the use of engineered barriers to ensure compliance with the requirements of 40 CFR Part 191 and 10 CFR Part 60 (see Appendix I of this Part).

§ 960.4–2 Technical guidelines.

The technical guidelines in this subpart set forth qualifying, favorable, potentially adverse, and, in five guidelines, disqualifying conditions on the characteristics, processes, and events that may influence the performance of a repository system after closure. The favorable conditions and the potentially adverse conditions under each guideline are *not* listed in any assumed order of importance. Potentially adverse conditions will be considered if they affect waste isolation within the controlled area even though such conditions may occur outside the controlled area. The technical guidelines that follow establish conditions that shall be considered in determining compliance with the qualifying condition of the postclosure system guideline. For each technical guideline, an evaluation of qualification or disqualification shall be made in accordance with the requirements specified in subpart B.

§ 960.4–2–1 Geohydrology.

(a) *Qualifying condition*. The present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation. The geohydrologic setting, considering the characteristics of and the processes operating within the geologic setting, shall permit compliance with (1) the requirements specified in § 960.4–1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered barrier system using reasonably available technology. (b) *Favorable conditions*. (1) Site conditions such that the pre-waste-emplacement groundwater travel time along any path of likely radionuclide travel from the disturbed zone to the accessible environment would be more than 10,000 years. (2) The nature and rates of hydrologic processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years. (3) Sites that have stratigraphic, structural, and hydrologic features such that the geohydrologic system can be readily characterized and modeled with reasonable certainty. (4) For disposal in the saturated zone, at least one of the following pre-waste emplacement conditions exists: (i) A host rock and immediately surrounding geohydrologic units with low hydraulic conductivities. (ii) A downward or predominantly horizontal hydraulic gradient in the host rock and in the immediately surrounding geohydrologic units. (iii) A low hydraulic gradient in and between the host rock and the immediately surrounding geohydrologic units. (iv) High effective porosity together with low hydraulic conductivity in rock units along paths of likely radionuclide travel between the host rock and the accessible environment. (5) For disposal in the unsaturated zone, at least one of the following prewaste-emplacement conditions exists: (i) A low and nearly constant degree of saturation in the host rock and in the immediately surrounding geohydrologic units. (ii) A water table sufficiently below the underground facility such that the fully saturated voids continuous with the water table do not encounter the host rock. (iii) A geohydrologic unit above the host rock that would divert the downward infiltration of water beyond the limits of the emplaced waste. (iv) A host rock that provides for free drainage. (v) A climatic regime in which the average annual historical precipitation is a small fraction of the average annual potential evapotranspiration. (c) *Potentially adverse conditions*. (1) Expected changes in geohydrologic conditions—such as changes in the hydraulic gradient, the hydraulic conductivity, the effective porosity, and the ground-water flux through the host rock and the surrounding geohydrologic units—sufficient to significantly increase the transport of radionuclides to the accessible environment as compared with pre-waste-emplacement conditions. (2) The presence of ground-water sources, suitable for crop irrigation or human consumption without treatment, along ground-water flow paths from the host rock to the accessible environment. (3) The presence in the geologic setting of stratigraphic or structural features—such as dikes, sills, faults, shear zones, folds, dissolution effects, or brine pockets—if their presence could significantly contribute to the difficulty of characterizing or modeling the geohydrologic system. (d) *Disqualifying condition*. A site shall be disqualified if the pre-waste emplacement ground-water travel time from the disturbed zone to the accessible environment is expected to be less than 1,000 years along any pathway of likely and significant radionuclide travel.

NOTE: The DOE will, in accordance with the general principles set forth in § 960.1 of these regulations, revise the guidelines as necessary, to ensure consistency with the final NRC regulations on the unsaturated zone, which were published as a proposed rule on February 16, 1984, in 49 FR 5934.

§ 960.4–2–2 Geochemistry.

(a) *Qualifying condition*. The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation. Considering the likely chemical interactions among radionuclides, the host rock, and the ground water, the characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4–1 for radionuclide releases to the accessible environment and (2) the requirements specified in 10 CFR 60.113 for radionuclide releases from the engineered-barrier system using reasonably available technology. (b) *Favorable conditions*. (1) The nature and rates of the geochemical processes operating within the geologic setting during the Quaternary Period would, if continued into the future, not affect or would favorably affect the ability of the geologic repository to isolate the waste during the next 100,000 years. (2) Geochemical conditions that promote the precipitation, diffusion into the rock matrix, or sorption of radionuclides; inhibit the formation of particulates, colloids, inorganic complexes, or organic complexes that increase the mobility of radionuclides; or inhibit the transport of radionuclides by particulates, colloids, or complexes. (3) Mineral assemblages that, when subjected to expected repository conditions, would remain unaltered or would alter to mineral assemblages with equal or increased capability to retard radionuclide transport. (4) A combination of expected geochemical conditions and a volumetric flow rate of water in the host rock that would allow less than 0.001 percent per year of the total radionuclide inventory in the repository at 1,000 years to be dissolved. (5) Any combination of geochemical and physical retardation processes that would decrease the predicted peak cumulative releases of radionuclides to the accessible environment by a factor of 10 as compared to those predicted on the basis of ground-water travel time without such retardation. (c) *Potentially adverse conditions*. (1) Ground-water conditions in the host rock that could affect the solubility or the chemical reactivity of the engineered-barrier system to the extent that the expected repository performance could be compromised. (2) Geochemical processes or conditions that could reduce the sorption of radionuclides or degrade the rock strength. (3) Pre-waste-emplacement groundwater conditions in the host rock that are chemically oxidizing.

§ 960.4–2–3 Rock characteristics.

(a) *Qualifying condition*. The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, chemical, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components. The characteristics of and the processes operating within the geologic setting shall permit compliance with (1) the requirements specified in § 960.4–1 for radionuclide releases to the accessible environment and (2) the requirements set forth in 10 CFR 60.113 for radionuclide releases from the engineered- barrier system using reasonably available technology. (b) *Favorable Conditions*. (1) A host rock that is sufficiently thick and laterally extensive to allow significant flexibility in selecting the depth, configuration, and location of the underground facility to ensure isolation. (2) A host rock with a high thermal conductivity, a low coefficient of thermal expansion, or sufficient ductility to seal fractures induced by repository construction, operation, or closure or by interactions among the waste, host rock, ground water, and engineered components. (c) *Potentially adverse conditions*. (1) Rock conditions that could require engineering measures beyond reasonably available technology for the construction, operation, and closure of the repository, if such measures are necessary to ensure waste containment or isolation. (2) Potential for such phenomena as thermally induced fractures, the hydration or dehydration of mineral components, brine migration, or other physical, chemical, or radiation-related phenomena that could be expected to affect waste containment or isolation. (3) A combination of geologic structure, geochemical and thermal properties, and hydrologic conditions in the host rock and surrounding units such that the heat generated by the waste could significantly decrease the isolation provided by the host rock as compared with pre-waste-emplacement conditions.

§ 960.4–2–4 Climatic changes.

(a) *Qualifying condition*. The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. In predicting the likely future climatic conditions at a site, the DOE will consider the global, regional, and site climatic patterns during the Quaternary Period, considering the geomorphic evidence of the climatic conditions in the geologic setting. (b) *Favorable conditions*. (1) A surface water system such that expected climatic cycles over the next 100,000 years would not adversely affect waste isolation. (2) A geologic setting, in which climatic changes have had little effect on the hydrologic system throughout the Quaternary Period. (c) *Potentially adverse conditions*. (1) Evidence that the water table could rise sufficiently over the next 10,000 years to saturate the underground facility in a previously unsaturated host rock. (2) Evidence that climatic changes over the next 10,000 years could cause perturbations in the hydraulic gradient, the hydraulic conductivity, the effective porosity, or the ground-water flux through the host rock and the surrounding geohydrologic units, sufficient to significantly increase the transport of radionuclides to the accessible environment.

§ 960.4–2–5 Erosion.

(a) *Qualifying condition*. The site shall allow the underground facility to be placed at a depth such that erosional processes acting upon the surface will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. In predicting the likelihood of potentially disruptive erosional processes, the DOE will consider the climatic, tectonic, and geomorphic evidence of rates and patterns of erosion in the geologic setting during the Quaternary Period. (b) *Favorable conditions*. (1) Site conditions that permit the emplacement of waste at a depth of at least 300 meters below the directly overlying ground surface. (2) A geologic setting where the nature and rates of the erosional processes that have been operating during the Quaternary Period are predicted to have less than one chance in 10,000 over the next 10,000 years of leading to releases of radionuclides to the accessible environment. (3) Site conditions such that waste exhumation would not be expected to occur during the first one million years after repository closure. (c) *Potentially adverse conditions*. (1) A geologic setting that shows evidence of extreme erosion during the Quaternary Period. (2) A geologic setting where the nature and rates of geomorphic processes that have been operating during the Quaternary Period could, during the first 10,000 years after closure, adversely affect the ability of the geologic repository to isolate the waste. (d) *Disqualifying condition*. The site shall be *disqualified* if site conditions do not allow all portions of the underground facility to be situated at least 200 meters below the directly overlying ground surface.

§ 960.4–2–6 Dissolution.

(a) *Qualifying condition*. The site shall be located such that any subsurface rock dissolution will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. In predicting the likelihood of dissolution within the geologic setting at a site, the DOE will consider the evidence of dissolution within that setting during the Quaternary Period, including the locations and characteristics of dissolution fronts or other dissolution features, if identified. (b) *Favorable condition*. No evidence that the host rock within the site was subject to significant dissolution during the Quaternary Period. (c) *Potentially adverse condition*. Evidence of dissolution within the geologic setting—such as breccia pipes, dissolution cavities, significant volumetric reduction of the host rock or surrounding strata, or any structural collapse—such that a hydraulic interconnection leading to a loss of waste isolation could occur. (d) *Disqualifying condition*. The site shall be *disqualified* if it is likely that, during the first 10,000 years after closure, active dissolution, as predicted on the basis of the geologic record, would result in a loss of waste isolation.

§ 960.4–2–7 Tectonics.

(a) *Qualifying condition*. The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. In predicting the likelihood of potentially disruptive tectonic processes or events, the DOE will consider the structural, stratigraphic, geophysical, and seismic evidence for the nature and rates of tectonic processes and events in the geologic setting during the Quaternary Period. (b) *Favorable condition*. The nature and rates of igneous activity and tectonic processes (such as uplift, subsidence, faulting, or folding), if any, operating within the geologic setting during the Quaternary Period would, if continued into the future, have less than one chance in 10,000 over the first 10,000 years after closure of leading to releases of radionuclides to the accessible environment. (c) *Potentially adverse conditions*. (1) Evidence of active folding, faulting, diapirism, uplift, subsidence, or other tectonic processes or igneous activity within the geologic setting during the Quaternary Period. (2) Historical earthquakes within the geologic setting of such magnitude and intensity that, if they recurred, could affect waste containment or isolation. (3) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or the magnitude of earthquakes within the geologic setting may increase. (4) More-frequent occurrences of earthquakes or earthquakes of higher magnitude than are representative of the region in which the geologic setting is located. (5) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such magnitudes that they could create large-scale surface water impoundments that could change the regional ground-water flow system. (6) Potential for tectonic deformations—such as uplift, subsidence, folding, or faulting—that could adversely affect the regional ground-water flow system. (d) *Disqualifying condition*. A site shall be disqualified if, based on the geologic record during the Quaternary Period, the nature and rates of fault movement or other ground motion are expected to be such that a loss of waste isolation is likely to occur.

§ 960.4–2–8 Human interference.

The site shall be located such that activities by future generations at or near the site will not be likely to affect waste containment and isolation. In assessing the likelihood of such activities, the DOE will consider the estimated effectiveness of the permanent markers and records required by 10 CFR Part 60, taking into account site-specific factors, as stated in §§ 960.4–2–8–1 and 960.4–2–8–2, that could compromise their continued effectiveness.

§ 960.4–2–8–1 Natural resources.

(a) *Qualifying condition*. This site shall be located such that—considering permanent markers and records and reasonable projections of value, scarcity, and technology—the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. (b) *Favorable conditions*. (1) No known natural resources that have or are projected to have in the foreseeable future a value great enough to be considered a commercially extractable resource. (2) Ground water with 10,000 parts per million or more of total dissolved solids along any path of likely radionuclide travel from the host rock to the accessible environment. (c) *Potentially adverse conditions*. (1) Indications that the site contains naturally occurring materials, whether or not actually identified in such form that (i) economic extraction is potentially feasible during the foreseeable future or (ii) such materials have a greater gross value, net value, or commercial potential than the average for other areas of similar size that are representative of, and located in, the geologic setting. (2) Evidence of subsurface mining or extraction for resources within the site if it could affect waste containment or isolation. (3) Evidence of drilling within the site for any purpose other than repository-site evaluation to a depth sufficient to affect waste containment and isolation. (4) Evidence of a significant concentration of any naturally occurring material that is not widely available from other sources. (5) Potential for foreseeable human activities—such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activities, or the construction of large-scale surface water impoundments—that could adversely change portions of the groundwater flow system important to waste isolation. (d) *Disqualifying conditions*. A site shall be disqualified if—(1) Previous exploration, mining, or extraction activities for resources of commercial importance at the site have created significant pathways between the projected underground facility and the accessible environment; or (2) Ongoing or likely future activities to recover presently valuable natural mineral resources outside the controlled area would be expected to lead to an inadvertent loss of waste isolation.

§ 960.4–2–8–2 Site ownership and control.

(a) *Qualifying condition*. The site shall be located on land for which the DOE can obtain, in accordance with the requirements of 10 CFR part 60, ownership, surface and subsurface rights, and control of access that are required in order that potential surface and subsurface activities as the site will not be likely to lead to radionuclide releases greater than those allowable under the requirements specified in § 960.4–1. (b) *Favorable condition*. Present ownership and control of land and all surface and subsurface rights by the DOE. (c) *Potentially adverse condition*. Projected land-ownership conflicts that cannot be successfully resolved through voluntary purchase-sell agreements, nondisputed agency-to-agency transfers of title, or Federal condemnation proceedings.

Appendix 6

Site-Suitability Criteria Proposed by the Goguel Committee in France

(Goguel 1987:57-62)

CHAPTER 5

Conclusions – Site Choice Technical Criteria
Reminder of the Main Recommendations

All throughout the report, the group's process has consisted of defining, where possible, criteria or recommendations common to all the geological environments considered generically.

However, the noticeable differences in particular of the hydrogeological, mechanical or thermal properties of these environments have often required distinguishing between them. From these considerations, specific to each type of formation, emerge a certain number of specific elements of which the evaluation is important to appreciate the safety of the storage before and after its closing; these are primarily:

- in the cases of crystalline rocks (granite and shale), the hydraulic role of the fractures; the abundance and the composition of the interstitial fluids;
- in the cases of salt formations, the characteristics of the covering; the presence and the nature of heterogeneities;
- in the cases of clay formations, the mechanical properties; the presence and the nature of heterogeneities.

In no case did the group seek to compare the environments amongst themselves. In fact, only the evaluation of the properties of a concrete site allows determining the quality of the geological barrier.

The parameters of a site entering in a complex manner into the analyses of safety to be presented for each site, the group deems meaningless to set critical numeric values for each parameter taken individually.

All useful data together, that is the subject of the site studies, should allow conducting a quantitative analysis showing that the safety objectives are respected. The file that will be the basis for this analysis should include all the numerical values of these parameters, their acquisition protocol, as well as the manner in which these data will be taken into account with their respective weight in the global modeling.

The group therefore endeavored exclusively to define and prioritize criteria that furnish a setting for the investigation to be undertaken and that will guide judgment for the evaluation of the sites proposed.

1 – CRITERIA AND MAIN RECOMMENDATIONS FOR THE CHOICE OF A SITE:

All the considerations developed in the previous chapters lead to highlighting a certain number of criteria or favorable factors for the choice of a geological storage site.

1.1) Essential criteria:

Among the site choice criteria, certain ones appear essential: it concerns hydrogeological properties of the site and its geological stability.

Hydrogeology

The general principle that should guide the choice of the sites being minimizing the groundwater flow, the first criteria must be a very low permeability of the host formation and a low gradient of regional hydraulic head.

The group recommends that a configuration preferably be sought for which the waters of the overlying aquifer formations are the site of a low hydraulic gradient.

The awareness of the regional hydrogeology is essential and must be dealt with in depth at each of the stages of the safety analysis. Hydrogeological measures must be carried out on a much wider area than the storage site so as to construct runoff models taking into account the flows from the recharge areas to the outlets. These regional plans must allow simulating the intensity and the direction of the underground flows.

Stability

The site chosen will have to be sufficiently stable so that the possible modifications of the initial conditions due to geological phenomena likely to be influential (glaciation, vertical movements, readjustments of active faults, earthquakes) remain acceptable with regard to the safety of the storage.

These phenomena will have to be evaluated for each proposed site qualitatively and quantitatively by relating to the current situation, to the recent past (historical) and especially to the most ancient part (Quaternary and potentially the end of the Pliocene). This will allow defining the value of the parameters characterizing them as well as their variations, and appreciating the influence of them on the site. For that it will be generally necessary to consider the regional geological environment of each site.

1.2) Important criteria

Other criteria play an important role and in particular: the mechanical properties of the host formation and the formations crossed by the utility access boxes, the geochemical properties of the geological barriers, the respect of a minimal depth, the non-sterilization of the underground resources as well as the thermal properties of the host formation and its surrounding rock.

Mechanical properties

They influence first of all the feasibility of the storage but also influence the pre- and post-closure.

The group recommends that the storage environment chosen, the design and the carrying out of the storage works allow avoiding any intervention for reversal of the template in the actual storage works during their filling.

Geochemical properties

They play an important role in the long term safety of the storage of radioactive waste because they can have an effect on the alteration of the artificial barriers, and that they govern the retention phenomena of the radionuclides possibly released.

Given the level acquired currently in the theoretical knowledge of the basic geochemical mechanisms, and provided that extensive in situ investigations are performed, the group thinks that it will be possible to supply a quantitative description of the geochemical properties of the system for the analysis of the conditions of transfer of the radionuclides.

The group recommends therefore that the main effort in this area be devoted to the investigations to conduct on the sites, that must be guided by rigorous experimental protocols adjusted to the requirements of the quantitative modelings and the specificities of the system, applying the methods and adapted available tools.

Respect of a minimal depth

The site will have to be chosen in such a way that the depth envisioned for the storage guarantees that the performances of confinement of the geological barrier not be affected significantly by the phenomena of erosion (in particular following glaciation), by the effect of an earthquake, or by the consequences of an "everyday" intrusion.

The group estimates that the thickness of the superficial area capable of being thus disrupted is in the range of 150 to 200 meters.

Sterilization of the groundwater resources

The site, in terms of the management of the subsoil, will have to be chosen so as to avoid sterilizing areas of which the known or suspected interest presents an exceptional character.

Thermal properties

The thermomechanical evolution of the environment depends evidently on the history of the heat release which is a parameter on which one can rely; the group recommends that studies be undertaken in particular using a modeling coupled with thermal and mechanical phenomena, in order to study the influence of the plan of distribution of wastes on the mechanical effects in the storage and in particular of preliminary cooling time and of the density of the storage of wastes.

The thermomechanical phenomena are well identified, but the group recommends doing specific studies, for each particular environment, allowing determining the corresponding physical parameters and specifying the influence of these phenomena. These studies must be done throughout the preliminary reconnaissance of the sites.

The group recommends performing some complete mineralogical analyses of the materials of the host formation and modeling their geochemical evolution in function of the temperature. The role of clay minerals in particular will be studied.

1.3) Favorable factors:

Additionally, certain favorable factors related to the site can if not influence, at least reinforce the choice of this site:

Dilution to the outlet

The application of the limitation system of the individual doses leads to giving priority to the sites having outlets with high flow in order to ensure a good dilution of the radioactivity potentially released at entry into the biosphere.

Distance to the outlet

The group finds it useful to give priority to the locations for which the flow lines between the storage and the outlet are the longest in order to contribute to delaying a potential transfer of radionuclides and increase the possibility of fixation of the elements in the rocks crossed.

Possibility of choice of a reasonable depth

The group remembered that the preceding criteria do not necessarily lead to the choice of the greatest depth possible. It feels that it is preferable for the area where the site will be situated to be able to offer a leeway of choices of depth to retain for the storage.

2 – OTHER RECOMMENDATIONS

2.1) Recommendations related to the reconnaissance of the site and its monitoring

The group recommends that the number of reconnaissance drilling sites from the surface be limited to the strict minimum compatible with the acquisition of knowledge sufficient for proceeding to the selection and the qualification of the site.

The group recommends that the reconnaissance of the site endeavor to detect the major faults of the rocky frame and to evaluate their neotectonic mobility.

The group recommends that the program of investigations of the site, before the operation of the storage, plan:

- the verification of the quality of the wells and the definition of a surveillance and maintenance procedure of these wells.
- the overall reconnaissance, by methods adapted to the site, of areas favorable for the creation of storage facilities for the planned nominal capacity of the site.

The group feels that it is essential to provide for an instrumentation adapted for the monitoring of the evolution of the parameters related to the site and to the works: this instrumentation will have to be implemented as soon as possible.

2.2) Recommendations related to the workflow of the storage

The group recommends studying the design of access wells so as to limit the risk of artificial circulation of the waters.

The group recommends that the techniques of digging tunnels and storage facilities be chosen so as to limit the extension of disturbances incurred in the environment at the vicinity of the walls of the works.

The concept of plans of retaining structures left in place upon the closing of a storage facility will have to take into account the requirements of long term safety, in particular for what concerns the disturbances brought to the environment. In particular, the consolidation methods used will have to be compatible with a suitable stopping of the storage facilities and the service tunnels.

The group recommends that the performance of techniques and implementation of the engineered barriers be verified by sufficiently large scale tests, in configurations representative of the storage facilities of wastes B and wastes C, and as a matter of priority for the cases of storage in hard rocks.

The group recommends that the conditions of closing of the cavities as well as the future and the influence of the volumes of air or trapped gases in the works and in particular in the backfill material be studied.

The group recommends that a reflection about the possible mastery of the combination of all the phenomena of fluid, rock and filling material be conducted for the purpose of improving the conditions of storage.

2.3) Recommendations related to the risk of human intrusion

The group recommends:

- defining on the ground a perimeter of protection to respect around the site and of which the extension will have to be determined according to its characteristics; inside this perimeter the works must be subject to authorization; in this respect a volume of exclusion will be able to be defined;
- integrating explicitly these measures in different existing or future texts of legislative or regulatory nature (decree of authorization of creation, right of way decrees, land use documents …).

The group recommends that the memory of storage be maintained in particular by a preservation as efficient as possible of the archives, and that the interest of arranging on the ground, on the surface, directly above the storage, some very visible and durable marks be examined.

The group recommends improving knowledge of certain parameters like the rate of leaching of the glasses or the coefficients of exchange between the groundwaters and the geological environment in order to be able to present over time a safety study regarding the risk of human intrusion.

All the thoughts and recommendations expressed in this report are based on the current state of knowledge that allows understanding reasonably the future of radionuclides in a storage site rigorously built and established in a properly selected geological environment. This implies the implementation of expertise and available scientific and technological means, as well as improvements that will be able to be brought by the continuation of studies carried out.

Appendix 7

Site-Suitability Criteria Proposed by AkEnd Commission in Germany

(AkEnd 2002:99-100)

Weighting Group 1: Quality of the isolation capacity and reliability of proof

1. No or slow radionuclide transport with groundwater at repository level

The field velocity of the groundwater in the isolating rock zone should be as low as possible, i.e. clearly below 1 mm per year. The isolating rock zone should consist of rock types which, according to experience, show low field hydraulic conductivity. The effective diffusion coefficient in the isolating rock zone should be as low as possible (less than 10^{-11} m^2/s).

2. Favorable configuration of host rock and isolating rock zone

The barrier rocks of the isolating rock zone must have a thickness that ensures the isolation of radionuclides for a period in the order of magnitude of one million years. The repository area and the host rock body should be surrounded by barrier rocks of the isolating rock zone. The top of the required isolating rock zone should be as deep as possible. The spatial extension of the isolating rock zone should be larger than the required volume calculated for the repository. The specific hydraulic gradient in the isolating rock zone should be low (less than 10^{-2}).

3. Good spatial characterizability

The rock types and their characteristics should spatially be as evenly distributed as possible within the isolating rock zone. The geological structure should show as little tectonic imprinting as possible. Its extent is derived from the structural situation with consideration of fault and fold tectonics. Salt rock structures should show large-scale folding of strata with different mechanical and hydraulic properties. Areas are favorable where the rocks of the isolating rock zone are uniform or very similar across an extensive area.

4. Good predictability

The features “thickness”, “extent” and “field hydraulic conductivity” of the isolating rock zone should not have changed essentially for several million years.

Weighting Group 2: Assurance of isolation capacity

5. Favorable rock-mechanic conditions

There should be a low tendency to mechanically induced secondary permeability outside a contour near deconsolidated border zone around the repository excavations.

6. Low tendency of the formation of water flow paths

The representative field hydraulic conductivity should be the same as the representative matrix hydraulic conductivity. The barrier effectiveness of the rock mass against the migration of liquids or gases (under geogenic and in part also under anthropogenic impacts) should be derivable from geoscientific, geotechnical or mining experience. Under in-situ conditions, the rock should naturally show a plasticviscous deformation ability without dilatancy. Upon stress inversion (increasing isotropic stress and decreasing deviatory stress), fissures/fissure systems in the rock should be closed in a geohydraulically effective manner. Following fissure closure, fissures/fissure systems in the rock should be healed in a geomechanically effective manner.

Weighting Group 3: Other safety-relevant characteristics

7. Good gas compatibility

Gas generation of the waste under disposal conditions should be as low as possible. The pressure build-up due to the expected gas generation of the waste should be low.

8. Good temperature compatibility

In the rock immediately surrounding the emplacement cavities, no mineral changes that would exert an inadmissible influence on the barrier effect of the isolating rock zone must occur if temperatures lie below 100°C. The tendency to thermomechanically induced secondary permeability outside a contour-near deconsolidated border zone should be as much spatially restricted as possible.

9. High radionuclide retention capacity of the rocks

The sorption capacity of the rocks should be as high as possible. The K_d-value for the majority of the long-term-relevant radionuclides should be greater than or equal to 0.001 m^3/kg. The rocks of the isolating rock zone should have the highest possible contents of mineral phases with a large reactive surface.

10. Favorable hydrochemical conditions

The deep groundwater in the host rock and in the isolating rock zone should be in chemical equilibrium with the rocks. Deep groundwater should have a pH value of 7-8. Favorable redox conditions should prevail in deep groundwater. The content of colloids in deep groundwater should be as low as possible. The content of complexing agents and the carbonate concentration in deep water should be low.

Appendix 8

Site-Suitability Criteria Adopted by the Nuclear Waste Management Organization in Canada

(NWMO 2010:33-35, 37)

Criteria to Ensure Safety

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Containment and isolation characteristics of the host rock	1. **The geological, hydrogeological, chemical and mechanical characteristics of the site should:** » promote long-term isolation of used nuclear fuel from humans, the environment and surface disturbances; » promote long-term containment of used nuclear fuel within the repository; and » restrict groundwater movement and retard the movement of any released radioactive material.	1.1 The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events. 1.2 The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities. 1.3 The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system. 1.4 The hydrogeological regime within the host rock should exhibit low groundwater velocities. 1.5 The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement. 1.6 The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Long-term stability of the site	2. The containment and isolation functions of the repository should not be unacceptably affected by future geological processes and climate changes, including earthquakes and glacial cycles.	2.1 Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term. 2.2 The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository. 2.3 The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository. 2.4 The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.
Repository construction, operation and closure	3. The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	3.1 The strength of the host rock and in-situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. 3.2 The soil cover depth over the host rock should not adversely impact repository construction activities. 3.3 The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.

FACTORS AFFECTING SAFETY	PERFORMANCE OBJECTIVES	EVALUATION FACTORS TO BE CONSIDERED
Human intrusion	4. The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	4.1 The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. 4.2 The repository should not be located within geological formations containing groundwater resources at repository depth that could be used for drinking, agriculture or industrial uses.
Site characterization	5. The characteristics of the site should be amenable to site characterization and site data interpretation activities.	5.1 The host rock geometry and structure should be predictable and amenable to site characteri-zation and site data interpretation.
Transportation	6. The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from storage sites to the repository site.	6.1 The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. 6.2 The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

Criteria to Assess Factors Beyond Safety

FACTORS BEYOND SAFETY	EVALUATION FACTORS TO BE CONSIDERED
Potential social, economic and cultural effects during the implementation phase of the project, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated against the extent to which positive and negative effects on the host community can be addressed during the implementation phase of the project, including the following areas: » Health and safety of residents and the community » Sustainable built and natural environments » Local and regional economy and employment » Community administration and decision-making processes » Balanced growth and healthy, livable community
Potential for enhancement of the community's and the region's long-term sustainability through implementation of the project, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated against the extent to which positive and negative effects of the project on long-term sustainability of the host community and region can be addressed in the following areas: » Health, safety and inclusiveness/cohesion of the community » Sustainable built and natural environments » Dynamic resilience of the economy » Community decision-making processes » Balanced growth and healthy, livable community
Potential to avoid ecologically sensitive areas and locally significant features, including factors identified by Aboriginal Traditional Knowledge	Sites will be evaluated for the following: » Ability to avoid ecologically sensitive areas and locally significant features
Potential for physical and social infrastructure to adapt to changes resulting from the project	Sites will be evaluated for the following: » The availability of physical infrastructure required to implement the project » The ability of the community, and the social infrastructure it has in place, to adapt to changes resulting from the project » The NWMO resources required to put in place physical and social infrastructure needed to support the project
Potential to avoid or minimize effects of the transportation of used nuclear fuel from existing storage facilities to the repository site	Sites will be evaluated for the following: » The availability of transportation routes (road, rail, water) and the adequacy of associated infrastructure and potential to put such routes in place » The availability of suitable safe connections and intermodal transfer points, if required, and potential to put them in place » The NWMO resources (fuel, people) and associated carbon footprint required to transport used fuel to the site » The potential for effects on communities along the transportation routes and at intermodal transfer points