

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel

A Report to Congress and the Secretary of Energy

October 2009

United States
Nuclear Waste Technical Review Board

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

October 30, 2009

The Honorable Nancy P. Pelosi
Speaker of the House
United States House of Representatives
Washington, DC 20515

The Honorable Robert C. Byrd
President Pro Tempore
United States Senate
Washington, DC 20510

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

Dear Speaker Pelosi, Senator Byrd, and Secretary Chu:

The U.S. Nuclear Waste Technical Review Board submits this report, *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*, in accordance with provisions of the Nuclear Waste Policy Amendments Act of 1987, Public Law 100-203. That law directs the Board to report its findings and recommendations to Congress and the Secretary of Energy at least two times each year. Congress created the Board to perform an ongoing independent evaluation of the technical and scientific validity of activities undertaken by the Secretary of Energy related to the management and disposal of high-level radioactive waste and spent nuclear fuel.

The Administration recently announced its intention to consider alternative waste management strategies. The enclosed report surveys and describes 30 technical and institutional attributes of nuclear waste programs in 13 countries. The report does not evaluate or make judgments about any of the programs. Rather the Board hopes that this survey and future reports on lessons learned from experiences in the United States and other countries will provide useful factual information for Congress and the Secretary as they consider options for managing high-level radioactive waste and spent nuclear fuel in the United States.

The Board looks forward to continuing its technical evaluation and to providing critical technical and scientific information to Congress and the Secretary that can be used to inform the decision-making process.

Sincerely,

{signed}

B. John Garrick
Chairman

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Acknowledgments

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In addition, reviewers from Belgium (1), Finland (1), Germany (2), Spain (1), Sweden (1), and the United Kingdom (1) asked to remain anonymous.

Any errors that remain are the responsibility of the Board.

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

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

The Board appreciates the permission granted by the International Atomic Energy Agency to use portions of its **Radioactive Waste Management Glossary,** ***2003 Edition, Publication 1155, (IAEA: Vienna, 2003).***

Overview

The creation of high-activity, long-lived radioactive waste is an inevitable consequence of generating electricity in nuclear power plants. It also is an inevitable consequence of engaging in a set of activities associated with national defense, ranging from propelling nuclear submarines to producing the fissionable materials needed to construct nuclear weapons. Early in the nuclear era, the very-long-term management and the ultimate disposition of those wastes was not a high priority. By the mid-1970s, however, most nuclear-capable nations had begun to focus more intently on developing plans to ensure over the very long term that the wastes would not endanger public health and safety or do serious damage to the environment.

Especially within the last decade, those efforts have benefitted from increasingly fruitful international cooperation and coordination. The International Atomic Energy Agency, an autonomous organization with a working relationship with the United Nations, carries out technical assistance programs and provides regulatory guidance to its members. It also supports the implementation of the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management,* a treaty signed by 55 entities, including all but five of the 31 nations that now operate nuclear power plants. Under the auspices of its Radioactive Waste Management Committee, the Nuclear Energy Agency, part of the Organization for Economic Cooperation and Development, has established a number of subsidiary bodies that sponsor multinational exchanges among 28 industrial democracies.[1]

Today, there is strong international consensus that a deep geologic repository used to dispose of high-activity, long-lived radioactive waste "provides a unique level and duration of protection"[2] of public health and safety and the environment. Such a system "takes advantage of the capabilities of both the local geology and the engineered materials to

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[1] Among those groups are the Forum on Stakeholder Confidence, the Advisory Bodies to Government, the Regulators' Forum, the Working Party on Decommissioning and Dismantling, and the Integration Group for the Safety Case of Radioactive Waste Repositories.

[2] Nuclear Energy Agency, Radioactive Waste Management Committee, "Moving Forward with Geological Disposal of Radioactive Waste: An NEA RWMC Collective Statement," NEA-6433, OECD, Paris, 2008, pp. 7, 14. The other two quotations in this paragraph come from the same source.

fulfill specific safety functions in a complementary fashion providing multiple and diverse barrier roles." Further, the international waste management community broadly agrees that developing a deep geologic repository is "technically feasible." However, the route and pace in moving toward deep underground disposition of high-activity, long-lived radioactive waste vary considerably among countries with nuclear programs. Only one deep geologic repository is operating today: the Waste Isolation Pilot Plant in New Mexico. Transuranic waste from the U.S. nuclear weapons production program is the sole material that can be disposed of in that facility.

The purpose of this report is to provide Congress, the Secretary of Energy, and other interested parties with up-to-date information on the status of selected national programs to manage high-activity, long-lived radioactive waste.[3] The report is not intended to provide a comprehensive and exhaustive survey of waste management programs in the 31 countries that now operate nuclear power plants. Instead the report examines programs in 13 selected countries, which account for 83 percent of worldwide nuclear power generating capacity. These countries illustrate well the broad range of options and considerations that structure national programs. Importantly, all of these efforts are relatively transparent, thereby engendering some confidence that the information provided here is reliable. Other countries that might have been selected were ultimately omitted from this survey because their programs are in their infancy or because the status of their programs could not be independently documented. In the future, the Board may update this survey and include additional national programs.

For each of the 13 national programs, the Board gathered detailed information on 30 program attributes. Some of the attributes address the programs' legal and institutional arrangements; others describe technical approaches that the programs have taken. (A definition of these attributes can be found starting on page 13.) These data are presented in a series of detailed tables, which were reviewed for accuracy by at least one and in some cases as many as three in-country experts. The rest of this section highlights the following program attributes.[4]

- Context
- Organizational form of the implementer
- Independent technical/program oversight
- Current practices
- Geological investigations
- Status of the site-selection process
- Health and safety requirements for disposal
- Anticipated start of repository operations

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[3] Most of this material consists of liquid and vitrified high-level radioactive waste (HLW) from reprocessing plants and spent nuclear fuel (SNF).

[4] The information contained in the tables found in the Overview section as well as in the detailed tables uses terminology provided by the in-country reviewers. Space limitations sometimes prevent expanding on the information provided.

Context

Commercial and defense spent nuclear fuel (SNF), high-level radioactive waste (HLW), long-lived heat-generating waste, wastes from research and isotope production reactors are all potential candidates for disposal in a deep geologic repository. But the magnitude of this task is best approximated by the capacity of a country's commercial nuclear power plants.

The 13 countries considered in the survey vary significantly in that respect (Table 1). Belgium, Finland, Spain, and Switzerland have few nuclear power plants; France, Japan, and the United States have a substantial number. Further, the countries' dependence on nuclear ranges from a small percentage of national electricity production to a large majority of it.

In some nations, commitments have been made to construct a large number of new reactors, while, in others, the commitments have been more modest. In still others, legal or *de facto* moratoria on building nuclear power plants are in place. Finally, in many nations, a linkage exists, sometimes informal and implicit, sometimes formal and explicit, between finding a "solution" to the radioactive waste management problem and continued operation (or new construction) of nuclear power plants.

Table 1

NUCLEAR-GENERATED ELECTRICITY*

COUNTRY	OPERATING NUCLEAR POWER PLANTS	CURRENT GENERATING CAPACITY (GIGAWATTS)	PERCENTAGE OF TOTAL ELECTRICITY PRODUCTION
United States	104	101.1	19.7
Belgium	7	5.7	53.8
Canada	18	12.7	14.8
China	11	8.6	2.2
Finland	4	2.7	29.7
France	58	63.5	76.2
Germany	17	20.3	28.3
Japan	53	46.2	24.9
Republic of Korea	20	17.7	35.6
Spain	8	7.4	18.3
Sweden	10	9.1	42.0
Switzerland	5	3.2	39.2
United Kingdom	19	11.0	13.5

*As of May 31, 2009.

Table 2

ORGANIZATIONAL FORM OF THE IMPLEMENTER		
COUNTRY	**IMPLEMENTING ORGANIZATION**	**ORGANIZATIONAL FORM**
United States	Department of Energy Office of Civilian Radioactive Waste Management	Government agency
Belgium	National Agency for Radioactive Waste and Enriched Fissile Materials	Government agency
Canada	Nuclear Waste Management Organization	Private corporation formed by the owners of nuclear fuel waste
China	China National Nuclear Corporation, provisionally	Government-owned corporation
Finland	Posiva Oy	Joint waste management company created by the owners of nuclear power plants
France	National Agency for Radioactive Waste Management	Government-owned Public Service Agency
Germany	Office for Radiation Protection within the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety	Government agency
Japan	Nuclear Waste Management Organization	Private nonprofit organization established by the owners of nuclear power plants
Republic of Korea	Korea Radioactive Waste Management Organization	Government agency
Spain	Spanish National Company for Radioactive Waste	Government-owned corporation
Sweden	Swedish Nuclear Fuel and Waste Management Company	Private corporation formed by the owners of nuclear power plants
Switzerland	National Cooperative for the Disposal of Radioactive Waste	Public/private consortium of radioactive waste producers, including the owners of nuclear power plants and the Federal State
United Kingdom	Nuclear Decommissioning Authority Radioactive Waste Management Division	Non-Departmental Public Body under the responsibility of the Department of Energy and Climate Change

Organizational Form of the Implementer

A broad international consensus exists among countries actively considering the very-long-term management of radioactive waste that establishing health, safety, and environmental standards for disposal and deciding whether a deep geologic repository should be sited, constructed, or operated are intrinsic governmental functions to be carried out by an independent regulator.[5] There is considerably less agreement on what is the most appropriate organizational form for the implementing entity responsible for repository siting, construction, and operation. In the United States, for example, even as Congress gave implementing responsibility to the Department of Energy, it authorized the creation of a special commission to make recommendations about alternative means for financing and managing that responsibility.[6] No particular organizational form dominates national choices (Table 2). Although the language that individual countries use to describe the organizational form varies, four distinct types of organizations have been created: government agencies, private corporations, government-owned corporations, and public-private partnerships.

[5] Although the regulatory responsibilities and arrangements vary from country to country, in all cases the regulator is an official governmental body. See Nuclear Energy Agency, "Regulating Long-Term Safety of Geologic Disposal," NEA-6182, OECD, Paris, 2007.

[6] U.S. Congress, Nuclear Waste Policy Act of 1982, Section 303. See also Advisory Panel on Alternative Means for Financing and Managing Radioactive Waste Facilities, "Managing Radioactive Waste—A Better Idea," December 1984.

Independent Technical/ Program Oversight

In addition to the implementer and the regulator, in many countries, a third type of organization has been created: the independent technical/program oversight body (Table 3). These organizations can make findings and recommendations to the responsible governmental agencies and branches of government or to the implementer; but they have no authority or control over either the implementer or the regulator. Some of these bodies consciously were established to bolster the credibility of other organizations charged with programmatic responsibilities. Others were created to institutionalize a "second opinion" into what are often technically and politically controversial activities. Further, these oversight bodies differ in their charters. Some focus exclusively on technical matters while others have a broader mandate, which includes waste management's ethical, legal, social, and policy dimensions as well as its technical ones.

Table 3

INDEPENDENT TECHNICAL/PROGRAM OVERSIGHT

COUNTRY	OVERSEER	ROLE
United States	Nuclear Waste Technical Review Board	Advises Congress and the Secretary of Energy
Belgium	None	
Canada	Independent Technical Review Group	Advises the Nuclear Waste Management Organization
China	No decision made.	
Finland	None	
France	National Review Board	Advises Government and Parliament
	Local Information and Oversight Committee	Advises National Agency for Radioactive Waste on the operation of the underground research laboratory at Bure
Germany	Nuclear Waste Management Commission	Advises the Ministry for the Environment, Nature Conservation, and Nuclear Safety
Japan	None	
Republic of Korea	None	
Spain	None	
Sweden	National Council for Nuclear Waste	Advises the Ministry of the Environment
Switzerland	Nuclear Safety Commission	Advises the Federal Council, the Department of the Environment, Transport, Energy, and Communication, and the Federal Nuclear Safety Inspectorate
United Kingdom	Committee on Radioactive Waste Management	Advises Government and the Devolved Administration Ministers

Table 4

CURRENT PRACTICES		
COUNTRY	**MATERIAL AUTHORIZED TO BE DISPOSED OF IN A DEEP GEOLOGIC REPOSITORY**	**INDEPENDENT CENTRALIZED STORAGE FACILITY ESTABLISHED**
United States*	High-level radioactive waste, commercial spent nuclear fuel, naval reactor fuel, Department of Energy spent nuclear fuel	No
Belgium	High-level radioactive waste	No
Canada	Commercial spent nuclear fuel	No
China	High-level radioactive waste	No
Finland	Commercial spent nuclear fuel	No
France	High-level radioactive waste and long-lived intermediate-level waste	No
Germany	High-level radioactive waste, commercial spent nuclear fuel, and heat-generating intermediate-level waste	Yes, at Gorleben and Ahaus
Japan	High-level radioactive waste	No
Republic of Korea	Commercial spent nuclear fuel	Envisioned, but no schedule for beginning to site such a facility has been established
Spain	No decision made.	A siting process for a Centralized Temporary Storage facility has been initiated.
Sweden	Commercial spent nuclear fuel	Yes, at Oskarshamn (CLAB)
Switzerland	High-level radioactive waste is the only form currently considered waste.	Yes, at Würenlingen (ZWILAG)
United Kingdom	High-level radioactive waste, commercial spent nuclear fuel, intermediate-level waste, and low-level waste not suitable for near-surface disposal. Uranium and plutonium if these elements are declared to be waste.	No

*Does not include waste authorized to be disposed of in the Waste Isolation Pilot Plant.

Current Practices

Until the mid-1970s, the nuclear power community worldwide believed that the fuel assemblies from commercial nuclear power plants would be removed when spent, cooled on-site for a relatively short period of time, and then sent to chemical reprocessing plants. At the reprocessing plants, the plutonium, created by neutron absorption, and the remaining uranium would be separated out and recycled into either light-water or fast reactors. The HLW from reprocessing plants would be vitrified and ultimately disposed of in a deep geologic repository. Adopting this approach meant that the nuclear fuel cycle was "closed."

In part out of concerns about nuclear-weapon materials proliferation, some nations subsequently adopted a nuclear fuel cycle that was "once-through"—that is, the SNF removed from reactors would be cooled, stored either on-site or at an independent centralized facility, and then disposed of directly in a deep geologic repository.

There is considerable variety in materials authorized for disposal in different countries (Table 4). The variety is, to a large degree, a reflection of nuclear-fuel-cycle choices, some of which are still in flux. Countries also vary in whether they have established an independent centralized storage facility either for HLW or SNF or for both forms of waste.

Geological Investigations

An influential 1957 report by the U.S. National Academy of Sciences' National Research Council identified geological disposal as a technically defensible option for the very-long-term management of HLW. Further, the report pointed to salt as an acceptable host rock because the presence of salt implied the absence of water and because the plasticity of salt would seal fractures that otherwise could preferentially conduct water flow through the waste emplacement zones.[7] This report provided the technical rationale that led the United States to focus almost exclusively until the mid-1970s on identifying a site in salt for a deep geologic repository.

Finding a salt formation where a repository might be sited was not an option, however, for many other countries. Sweden, for example, began to explore the possibility of disposing of its waste in granite, which underlies most of that country's landscape. Out of that exploration eventually came the KBS-3 approach: SNF first is encapsulated in copper, and the copper canisters then are placed in granite basement rock at a depth of about 500 meters and surrounded by bentonite clay. The acceptance by the radioactive waste disposal community that a *combination* of geological and engineered barriers might provide sufficient protection of public health and safety and the environment opened the door to investigate a large number of potential host rocks.[8] Indeed, even countries that are thinking about or actually developing a deep geologic repository in clay, and thus believe there is no need for a robust engineered barrier system, take a systems approach in developing their safety cases.

Table 5

GEOLOGICAL INVESTIGATIONS

COUNTRY	GEOLOGIC ENVIRONMENTS CONSIDERED OR INVESTIGATED	INDIGENOUS UNDERGROUND RESEARCH LABORATORY ESTABLISHED
United States	Salt, basalt, granite, tuff, clay, and shale	The Exploratory Studies Facility at Yucca Mountain served the function of an underground research laboratory (tuff).
Belgium	Clay and shale	Mol (clay)
Canada	Granite and sedimentary rock	Pinawa (granite)*
China	Granite	None
Finland	Granite, gneiss, grandiorite, and migmatite	Construction of ONKALO underground rock characterization facility in Eurajoki began in 2004 and is continuing (granite).
France	Argillite and granite	Bure (argillite)
Germany	Salt	Gorleben (salt)
Japan	Granite and sedimentary rock	Tono (granite) Mizunami (granite) Horonobe (sedimentary rock)
Republic of Korea	Granite	Korea Underground Research Tunnel (granite)**
Spain	Granite, clay, and salt	None
Sweden	Granite	Äspö (granite)
Switzerland	Clay and granite	Mont Terri (clay) and Grimsel (granite)
United Kingdom	No decision made.	None

*In the process of being decommissioned

**At shallow depth only

Numerous types of rock have been considered or have been investigated, and many countries have constructed an indigenous underground research laboratory to carry out *in situ* investigations of a formation's potential to isolate and contain radioactive waste (Table 5).

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[7] National Research Council, *The Disposal of Radioactive Waste on Land*, (Washington, D.C.: National Academy of Sciences Press, 1957).

[8] The United States abandoned its salt-centric siting strategy in 1976. Studies by the U.S. Geological Survey and the American Physical Society argued that what matters is the performance of the entire system of geological and engineered barriers. This view was adopted for the most part in 1979 by an interagency group created by President Jimmy Carter to develop an Administration-wide policy on managing radioactive waste. See Interagency Review Group on Nuclear Waste Management, *Report to the President*, (TID-29442), Washington D.C., 1979.

Table 6

STATUS OF THE SITE-SELECTION PROCESS	
COUNTRY	**STATUS**
United States	Site at Yucca Mountain was selected.*
Belgium	Formal siting process not initiated.
Canada	Siting process initiated.
China	Preliminary investigations underway at Beishan in the Gobi Desert.
Finland	Site at Olkiluoto near the municipality of Eurajoki has been selected.
France	Site near the village of Bure has been selected.**
Germany	Siting process on hold.
Japan	Siting process initiated.
Republic of Korea	Formal siting process not initiated.
Spain	Formal siting process not initiated.
Sweden	Site in the municipality of Östhammar was selected.
Switzerland	Siting process initiated.
United Kingdom	Siting process initiated.

*The Administration recently indicated its intention to terminate funding for the Yucca Mountain repository program and to appoint a Blue Ribbon Commission to consider nuclear waste management alternatives. To date, licensing hearings before the Nuclear Regulatory Commission continue.

**A 250-square-kilometer area has been identified. The selection of a specific location within that area for development as a deep geologic repository is under way.

Status of the Site-Selection Process

Experience over the years in many countries has made clear that potential deep geologic repository sites have to pass through both a technical filter and a political filter. Some countries identify potential sites based first on technical considerations and then determine whether political realities will permit the site's development as a repository. Other countries reverse the order, looking first for volunteer communities and then evaluating a site's technical merits. Still other countries have concluded that moving forward at this time is simply premature.

Experience over the years also has made clear that a siting process can get bogged down because either technical or political obstacles have arisen. In some countries, programs have had to be altered fundamentally to overcome either barrier or both barriers. These reorganizations have, at the very least, resulted in significant programmatic delays. In other countries, technical or political controversies, or the prospects of them, have lead policy-makers to defer for many decades the development of a deep geologic repository. Table 6 provides information on the status of the site-selection process in the 13 nations considered here.

Health and Safety Requirements for Disposal

Although a deep geologic repository can provide a unique level and duration of protection, questions remain in many countries about what the protective level should be, how standards should be formulated, how long the duration should last, what methodology should be used to judge compliance, and what the spatial domain should be where the regulation is enforced. Further, in some countries, the regulations are very prescriptive, and in others, they are very general, providing only broad guidelines for the implementer.

Three aspects of the regulations seem to be of particular importance. In the terminology used by the radioactive waste management community, the minimal acceptable protective level is measured by either a dose constraint or a risk limit. The dose constraint is the effective dose or the equivalent dose to individuals that may not be exceeded. The dose constraint is usually measured in millisieverts per year.[9] No consensus obtains on the definition of a risk limit. Typically, however, the term is taken to mean the probability of a person living in the vicinity of a repository suffering genetic or serious health effects, including cancer, during the course of his or her lifetime as a result of radioactive material released from the repository.[10] The risk limit is always measured in terms of the probability per year, for example, one in a million or 10^{-6}/year. Finally, the duration over which the regulation applies is measured by a compliance period. These regulatory choices represent social judgments informed by technical analyses.[11]

Some of the 13 nations discussed in this report have not yet established radiological health and safety requirements for the disposition of radioactive waste. Among those that have, there are some important similarities and differences (Table 7). If one looks only at the first 10,000 years after repository closure, all the countries regard as acceptable a dose

Table 7

HEALTH AND SAFETY REQUIREMENTS FOR DISPOSAL

COUNTRY	DOSE CONSTRAINT	RISK LIMIT	COMPLIANCE PERIOD
United States	0.15 mSv/year	Not specified	Less than 10,000 years
	1.0 mSv/year*	Not specified	Greater than 10,000 years but less than 1,000,000 years
Belgium	Expected to be 0.1–0.3 mSv/year	Not specified	May be as much as 1,000,000 years
Canada	An upper limit of 1.0 mSv/year established; 0.3 mSv/year proposed.	Not specified	Not specified
China	No decision made.	No decision made.	No decision made.
Finland	Less than 0.1 mSv/year. Release limits for various radionuclides established.	Not specified	First several thousand years
	Impacts should be comparable to those arising from natural radioactive materials but should remain insignificantly low.	Not specified	Beyond first several thousand years.
France	0.25 mSv/year for normal scenarios.	Not specified	10,000 years
Germany	Not specified	Less than 10^{-4}/lifetime for probable scenarios; Less than 10^{-3}/lifetime for less probable scenarios	1,000,000 years
Japan	No decision made.	No decision made.	No decision made.
Republic of Korea	No decision made.	No decision made.	No decision made.
Spain	No decision made.	No decision made.	No decision made.
Sweden	Not specified	Less than 10^{-5}/year	100,000 years
Switzerland	Complete containment	Not specified	1,000 years
	0.1 mSv/year for probable scenarios	Not specified	As much as 1,000,000 years
	Not specified	Less than 10^{-6}/year for less probable scenarios	As much as 1,000,000 years
United Kingdom	No decision made.	Guidance calls for less than 10^{-6}/year.	No decision made.

*Applicable only to a repository constructed at Yucca Mountain.

[9] One millisievert (mSv) equals 100 millirems.

[10] This definition is consistent with how the term is used by the International Commission on Radiological Protection and the regulators in Germany and the United Kingdom.

[11] In addition to satisfying regulatory requirements for protecting public health and safety, the implementing organization typically has to prepare environmental impact assessments and have them approved by relevant governmental authorities.

constraint that falls within a range of 0.1–0.3 mSv/year. However, some of those countries require that the dose constraint also be satisfied for compliance periods that extend as far out as 1,000,000 years. Risk limits span a similarly large range—10^{-3} to 10^{-6}/year—depending on the compliance period and the likelihood that a particular scenario evolves.

Table 8

ANTICIPATED START OF REPOSITORY OPERATIONS	
COUNTRY	**DATE**
United States	No decision made.*
Belgium	Anticipated in roughly the 2040 time-frame.
Canada	No decision made.
China	Anticipated in roughly the 2050 time-frame.
Finland	2020
France	2025
Germany	No decision made.
Japan	No decision made.
Republic of Korea	No decision made.
Spain	No decision made.
Sweden	2023
Switzerland	No sooner than 2040
United Kingdom	No decision made.

*The Administration recently indicated its intention to terminate funding for the Yucca Mountain repository program and to appoint a Blue Ribbon Commission to explore nuclear waste management alternatives. To date, licensing hearings before the Nuclear Regulatory Commission continue.

Anticipated Start of Repository Operations

Three of the four countries that have selected a site for a deep geologic repository—Finland, France, and Sweden—have announced when they anticipate the start of operations: they all expect to begin emplacing radioactive waste within roughly the next 10 to 15 years (Table 8). Three other countries have projected a time 30 to 40 years from now, although only one of them, Switzerland, has initiated a formal siting process. The remaining seven nations have made no decision about when repository operations will begin, either because the timing depends on finding a volunteer community and reaching an agreement with it or because a formal siting process is on hold or has not been initiated.

A Concluding Comment

When the radioactive waste management community in the United States and abroad began work on developing a deep geologic repository, the task was perceived to be a simple one. A technically suitable site would first be identified. Then scientific and engineering talents would be mustered to complete what was viewed as a relatively straightforward construction project. Since then, it has become clear that performing convincing technical analysis in the face of considerable temporal and spatial uncertainties is more complex and challenging than earlier anticipated. Creating a supportive institutional environment—founding credible implementing and regulatory agencies, creating trusting relationships with local communities, and putting into place legitimate decision-making processes—has proven to be challenging as well. That many national programs have had to be reconstituted in fundamental ways is testimony to the difficulties encountered over the years.

With only the three countries identified above close to implementing a technically and politically accepted effort to develop a deep geologic repository, it is difficult to infer what, if anything, is a "magical recipe" for success. This question, however, will be explored in greater depth in a subsequent Board report. At this point, we simply note that these 13 countries are strongly committed to managing radioactive waste for the very long term in ways that do not impose burdens on future generations. The precise path taken by each will strongly depend on its technical and political cultures. In the end, it may very well be that the many paths all lead to the same outcome: successful disposal of long-lived, high-activity radioactive waste in a deep geologic repository.

Detailed Tables

The Board identified 30 key attributes associated with national radioactive waste management programs. Half of them relate to the institutional arrangements that have been established in each country. The other attributes relate to the technical approaches that have been adopted. Detailed tables containing information about the attributes, which appear as column headings, were then constructed using official documents released by each nation. Most helpful were a series of reports submitted to the International Atomic Energy Agency as part of the Third Meeting held under the provisions of the *Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management.*

Drafts of the detailed tables were sent out to in-country experts for peer review. At least one expert from each country, and as many as three, reviewed the tables and provided comments. (Reviewers that wished to be recognized are acknowledged in the beginning of this report.) The comments were incorporated, and the tables were revised. Typically, the comments filled in "blanks" on the draft tables, updated the information contained in the drafts, and provided more information than could be found in the official documents. Every effort was made to harmonize the various table entries so that their meaning would be consistent across countries. To achieve that end, definitions for the 30 attributes were developed. These definitions are provided below.[12]

To facilitate the viewing of the detailed tables, they are laid out so that the information for three countries is grouped together. The attributes related to institutional arrangements for each group are presented first followed by the attributes related to technical approaches. With the exception of the United States, the nations are grouped in alphabetical order. Each group is color-coded so that the reader can quickly locate any country of interest.

[12] In the detailed tables, the reader will find two entries that appear similar on their face: "no decision made" and "none." When the first entry is encountered, it should be interpreted to mean that the country has not addressed the particular attribute either implicitly or explicitly. When the second entry is encountered, it should be interpreted to mean that the country has made the decision indicated in the table.

KEY ATTRIBUTES—INSTITUTIONAL ARRANGEMENTS

1. *Legislation specific to radioactive waste management:* Laws passed that establish the rules under which radioactive waste will be managed.

2. *Implementing organization:* The entity charged under the law with the responsibility for siting, constructing, and operating facilities for managing radioactive waste.

3. *Independent regulator:* The entity charged under the law with the responsibility for establishing health, safety, and environmental standards for managing radioactive waste and for approving/disapproving or recommending for approval/disapproval the licensing of facilities for managing radioactive waste.

4. *Independent technical/program oversight:* Entities that are independent of the implementer and the regulator that provide advice on technical and other issues associated with the management of radioactive waste. The entities can give their advice to the Government, the legislature, or the implementer. They can be appointed either by the Government or the implementer.

5. *Dedicated funding source for repository development:* Money, segregated from general government revenues, that finances the siting, construction, and operation of a deep geologic repository and other facilities. The source of the money may be payments by waste generators directly or by the users of nuclear-generated electricity.

6. *Regulations and decrees applicable to licensing a deep geologic repository—site-selection:* Rules and standards created by government agencies and Ministries that structure the processes used to choose a candidate or final location for a deep geologic repository.

7. *Regulations and decrees applicable to licensing a deep geologic repository—environmental impact assessment:* Rules and standards created by government agencies and Ministries that structure the processes and the required analysis for evaluating the environmental effects of developing a deep geologic repository.

8. *Regulations and decrees applicable to licensing a deep geologic repository—health and safety protection:* Rules and standards created by government agencies and Ministries that structure the processes and the required analysis for evaluating whether a proposed deep geologic repository is likely to comply with applicable requirements for protecting public health and safety.

9. *Formal legislative/executive approvals required for developing a deep geologic repository—selection of a waste management option:* Decisions about whether to develop a deep geologic repository or to adopt some other option, such as separation and transmutation or storage, for the very-long-term management of radioactive waste. The decision is made using political, as opposed to administrative, processes. It may occur before or after a regulatory decision or the submission of regulatory advice to the legislature or Government.

10. *Formal legislative/executive approvals required for developing a deep geologic repository—site-selection:* The decision to choose a candidate or final location for a deep geologic repository. The decision is made using political, as opposed to administrative, processes. It may occur before or after a regulatory decision or the submission of regulatory advice to the legislature or Government.

11. *Formal legislative/executive approvals required for developing a deep geologic repository—facility construction and operation:* The decision to permit the construction and operation of a deep geologic repository. The decision is made using political, as opposed to administrative, processes. It may occur before or after a regulatory decision or the submission of regulatory advice to the legislature or Government.

12. *Interactions with local jurisdictions—local veto:* Legally prescribed rules under which either a locality must give its approval before an action is taken (usually the selection of a site for a deep geologic repository) or the locality can reject a decision after it has been made.

13. *Interactions with local jurisdictions—limitations on local veto:* Legally prescribed rules under which any veto power held by local jurisdictions can be overridden or otherwise modified.

14. *Interactions with local jurisdictions—benefits to be provided to local community for accepting a facility:* Benefits include, among other things, dedicated tax and other payments, increased governmental services, and infrastructure development. Benefits may be legally prescribed or established through negotiations.

15. *Explicit adoption of a staged decision-making process:* Almost by necessity, the development of a deep geologic repository must take place in stages. However, some national programs are designed to require at every step intensive deliberation, recursive safety case evaluations, and explicit consideration of the option of not proceeding.

KEY ATTRIBUTES—TECHNICAL APPROACHES

1. *Operating nuclear power plants/generating capacity:* The number and gross generating capacity (in gigawatts electric) of plants operating as of May 31, 2009. The number of plants under construction is defined as the projects that have broken ground as of May 31, 2009. The generating capacity of those plants is the nominal capacity reported to authorities.

2. *Reprocessing included in fuel cycle:* Whether SNF has ever been reprocessed, either in the country or in a facility located outside of the country.

3. *Transportation system in place to move SNF/HLW to a deep geologic repository:* Transportation options available for those countries where a site has been selected or where particular sites are being actively considered.

4. *Independent centralized interim storage facility established:* Facilities that fall into this category store SNF or HLW from more than one generator. Such facilities are distinguished from storage installations at either operating or shut-down nuclear power or reprocessing plants.

5. *Geologic environments considered or investigated for a repository:* Host rocks that appear to be potentially suitable for a repository. The hosts rocks may have been considered or investigated in bench or desk studies, by surface investigation, or by at-depth exploration.

6. *Indigenous underground research laboratories:* Laboratories that have been created (either operational or under construction) where experiments can be conducted to evaluate the long-term suitability of a particular host rock to isolate and contain radioactive waste. Experiments conducted in another country's underground research laboratory are not included.

7. *Status of site-selection process:* The stage of the national decision for selecting a site for a deep geologic repository.

8. *Long-term health and safety requirements:* Specific regulations and standards establishing dose constraints, risk limits, and compliance periods that must be satisfied before a deep geologic repository can be licensed.

9. *Requirements for retrievability:* Specific laws or regulations establishing the time period within which waste must be able to be retrieved from a deep repository. Also specific laws and regulations establishing how the entire disposal process can be reversed.

10. *Requirements for defense-in-depth:* Specific laws or regulations establishing the degree to which various barriers must be able to isolate and contain radioactive waste independently of other barriers.

11. *Methodology for demonstrating compliance with postclosure standards:* Approaches the implementer must use to conduct its performance assessment or to advance its safety case for licensing a deep geologic repository.

12 *Engineered barrier system—design:* How the man-made part of the deep geologic repository system is to be constructed.

13. *Engineered barrier system—importance to safety case:* In comparison to the natural system (host rock, near-field environment, hydrogeology, and other factors), the role of the engineered barrier system in isolating and containing radioactive waste.

14. *Waste forms authorized to be disposed of in a deep geologic repository:* The type of material that would be required to be disposed of in a deep geologic repository.

15. *Anticipated start of repository operations:* Year in which either the implementer or an appropriate governmental authority has stated publicly that a deep geologic repository will be available to begin to accept waste for disposal.

United States, Belgium, Canada

Institutional Arrangements

	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
United States*	Nuclear Waste Policy Act (1982) Nuclear Waste Policy Amendments Act (1987) Energy Policy Act (1992)	Department of Energy Office of Civilian Radioactive Waste Management (Government agency)	Environmental Protection Agency (Sets environmental standards) Nuclear Regulatory Commission (Implements standards and licenses facilities)	Nuclear Waste Technical Review Board (Advises Congress and the Secretary of Energy)	Nuclear Waste Fund Generators of nuclear electricity pay a $0.001 per kilowatt-hour surcharge into the Fund.
Belgium	Law of 8 August 1980, modified by Law of 11 January 1991 and Law of 12 December 1997 [Implementation] Law of 29 March 1958, modified by Law of 15 April 1994 [Regulation]	National Agency for Radioactive Waste and Enriched Fissile Materials (Government agency)	Federal Agency for Nuclear Control	None	Long-Term Fund Costs of developing a repository will be fully paid by waste generators.
Canada	Nuclear Fuel Waste Act (2002) Nuclear Safety and Control Act (2000)	Nuclear Waste Management Organization, subject to Government approval of key policies and decisions (Private corporation formed by the owners of nuclear fuel waste)	Canadian Nuclear Safety Commission	Independent Technical Review Group (Advises the Nuclear Waste Management Organization)	Nuclear Fuel Waste Act Trust Fund Owners of nuclear power plants pay money into the Fund, subject to the formula approved by Government.

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

Institutional Arrangements

	Regulations and Decrees Applicable to Licensing a Deep Geologic Repository			Formal Legislative/Executive Approvals Required for Developing a Deep Geologic Repository		
	Site-Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site-Selection	Facility Construction and Operation
United States*	Nuclear Regulatory Commission 10CFR60 Department of Energy 10CFR960 and 10CFR963 (Radioactive waste-specific)	Council of Environmental Quality 40CFR1500 (Generic)	Nuclear Regulatory Commission 10CFR60 and 10CFR63 Environmental Protection Agency 40CFR191 and 40CFR197 (Radioactive waste-specific)	Department of Energy Generic Environmental Impact Statement (1980) Nuclear Waste Policy Act (1982)	Congressional approval of the Yucca Mountain site recommendation by President (2002)	After approval by the Nuclear Regulatory Commission of licenses to construct and possess/receive waste, no further action is required.
Belgium	Decision by the Council of Ministers limiting siting activities for a low- and intermediate-level waste repository to nuclear or non-nuclear volunteering sites No specific law for HLW/SNF repository (Radioactive waste-specific)	Strategic Environmental Assessment (Law 13 of February 2006) (Radioactive waste-specific)	Federal Agency for Nuclear Control Royal Decree of 20 July 2001 GRR-2001 (Radioactive waste-specific)	Strategic Environmental Assessment (Law 13 of February 2006) triggered the development of a Waste Plan by National Agency for Radioactive Waste and Enriched Fissile Materials, but no decision has been made.	No decision made.	Construction and operating licenses granted by Government through a Royal Decree on the advice of Federal Agency for Nuclear Control.
Canada	Canadian Nuclear Safety Commission Regulations under the Nuclear Safety and Control Act Clauses 3 and 4 (Nuclear facility-specific) Geological Considerations in Siting a Repository for High-Level Radioactive Waste R-72 (Radioactive-waste specific)	Regulations under the Canadian Environmental Assessment Act (Generic)	Canadian Nuclear Safety Commission Regulatory Guide G-320 (Radioactive waste-specific)	Government approved a recommendation by the Nuclear Waste Management Organization to implement a geologic disposal strategy of Adaptive Phased Management. An optional strategy of shallow underground storage also was adopted. (2007)	Once the Federal Minister of the Environment approves the environmental assessment, the Canadian Nuclear Safety Commission has the full authority to decide on the Site Preparation License.	After the approval by the Canadian Nuclear Safety Commission of licenses to construct and possess/receive waste, no further action is required.

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

Institutional Arrangements

	Interactions with Local Jurisdictions			Explicit Adoption of a Staged Decision-Making Process
	Local Veto	Limitations on Local Veto	Benefits to be Provided to Local Community for Accepting a Facility	
United States*	Yes, by governor	State veto can be exercised only when President recommends site for Congress's approval. Veto can be overridden by majority vote in both Houses of Congress	A schedule for providing benefits to the State of Nevada and to any state or tribe hosting a centralized interim storage facility or a repository was included in the Nuclear Waste Policy Amendments Act. Nevada has never requested benefits.	No
Belgium	No decision made for HLW/SNF repository. No formal legal right of veto for low- and intermediate-level waste disposal site. But without the agreement of the local partnership, the disposal facility will not be built. Volunteer nuclear community (Dessel) agreed to host a low- and intermediate-level waste disposal site.	No decision made for HLW/SNF repository. "Gentleman's agreement" that a low- and intermediate-level waste disposal facility will not be sited without community consent. As the project develops, implementer can veto decisions by the local community that adversely affect safety.	No decision made for HLW/SNF repository. None provided to date for low- and intermediate-level waste disposal facility. Discussions are on-going about providing benefits in the future.	No decision made. Expectation is that the process will be flexible and iterative.
Canada	Under the Adaptive Phased Management strategy, only communities willing to host a geologic repository will be considered.	No decision made.	No decision made.	Yes

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

Technical Approaches

	Operating Nuclear Power Plants/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a Deep Geologic Repository	Independent Centralized Interim-Storage Facility Established	Geologic Environments Considered or Investigated for a Repository
United States*	104 nuclear power plants (101.1 GWe) One nuclear power plant is under construction. (1.2 GWe)	The U.S. reprocessed SNF as part of its weapons plutonium production program. Small amounts of commercial SNF were reprocessed at West Valley, N.Y. Two other commercial reprocessing plants were constructed but never operated. The U.S. does not currently reprocess commercial SNF.	Depends on where the repository is developed. No rail transportation system is available for the Yucca Mountain site.	No	Salt, basalt, tuff, granite, clay, and shale
Belgium	Seven nuclear power plants (5.7 GWe) Additional nuclear power plants and operation beyond 40 years for existing nuclear power plants were prohibited in 2003.	Commercial SNF was reprocessed at La Hague. Moratorium on new reprocessing contracts was instituted in 1993 and confirmed in 1998 by the Council of Ministers. A small amount of commercial SNF was reprocessed by the pilot facility Eurochemic in Dessel.	No decision made.	No	Clay and shale
Canada	18 nuclear power plants (12.7 GWe)	No	No decision made.	No	Granite or sedimentary rock

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

Technical Approaches

	Indigenous Underground Research Laboratories	Status of Site-Selection Process	Long-Term Health and Safety Requirements	Requirements for Retrievability	Requirements for Defense-in-Depth
United States*	The Exploratory Studies Facility at the Yucca Mountain site served the function of an underground research laboratory. (Tuff)	The Yucca Mountain site has been characterized and was approved by Congress in 2002. The Administration has recently indicated its intention to terminate funding for the Yucca Mountain repository program and to appoint a Blue Ribbon Commission to explore nuclear waste management alternatives. Licensing hearings before the Nuclear Regulatory Commission continue.	For Yucca Mountain: 0.15 mSv/year for 10,000 years; 1 mSv/year thereafter up until 1,000,000 years. For any other site: 0.15 mSv/year for 10,000 years.	Within 50 years from the start of waste emplacement	Multiple barriers (both natural and engineered) required. No requirement for defense-in-depth or redundancy.
Belgium	HADES Project initiated in 1974 in Mol. (Clay)	No active siting process for a HLW/SNF repository being carried out.	No decision made. Dose constraint expected to be in the range 0.1–0.3 mSv/year. Compliance period may be as long as 10^6 years	No decision made.	No decision made. Safety philosophy includes defense-in-depth and some degree of redundancy in barrier function.
Canada	Pinawa Laboratory in Manitoba. (Granite) (In the process of decommissioning)	The Nuclear Waste Management Organization has proposed a process for selecting a site. No schedule has been set to complete the site-selection process.	Canadian Nuclear Safety Commission has specified a public dose limit of 1 mSv/year. Implementer is required to provide rationale for dose constraint. An example of a proposed dose constraint is 0.3 mSv/year.	The Adaptive Phased Management plan includes "potential for retrievability of the used fuel for an extended period, until such time as a future society makes a determination on the final closure and the appropriate form and duration of postclosure monitoring." This requirement has not yet been incorporated into regulations.	The Adaptive Phased Management plan recognizes the value of multiple barriers and redundant systems. This recognition has not yet been translated into regulations.

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

Technical Approaches

	Methodology for Demonstrating Compliance with Postclosure Standards	Engineered Barrier System		Waste Forms Authorized to be Disposed of in a Deep Geologic Repository	Anticipated Start of Repository Operations
		Design	Importance to Safety Case		
United States*	Mean value of Monte Carlo realizations generated by a probabilistic Total System Performance Assessment	Double-shelled waste package composed of Alloy 22 (outer) and carbon steel (inner); titanium drip shield	Very important	Vitrified commercial and defense HLW, commercial SNF, Navy SNF, and DOE SNF	No decision made.
Belgium	No decision made. A host-rock specific (Boom clay) performance assessment (SAFIR-2) has been carried out (2001): • Evaluation of normal scenario and altered scenarios • Some probabilistic elements • 0.3 mSv/year dose constraint • Calculations carried out to at least 10^6 years	Current reference design developed after SAFIR-2 considers stainless steel canisters holding HLW and a carbon steel overpack surrounded by thick concrete. The so-called Supercontainer is placed in concrete-lined drifts and backfilled with cementitious materials.	Relatively unimportant, although preliminary safety assessments do not support conclusively the isolation and containment capacity of Boom clay. (SAFIR-2)	Only HLW because SNF is not considered "waste." However, National Agency for Radioactive Waste and Enriched Fissile Materials must study geological disposal for both HLW and SNF.	No decision made. Likely to be in the 2040 time-frame.
Canada	According to the Canadian Nuclear Safety Commission Regulatory Guide G-320, an applicant to site, construct, or operate a geologic repository can choose among the following methodologies in developing its safety case: • Scoping assessments • Bounding assessments • Realistic best estimates of performance • Conservative calculations • Deterministic or probabilistic calculations	No decision made.	No decision made.	Commercial SNF	No decision made.

* Does not include institutional arrangements for the Waste Isolation Pilot Plant.

China, Finland, France

Institutional Arrangements

	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
China	Law of the People's Republic of China on Prevention and Control of Radioactive Pollution (2003)	China National Nuclear Corporation (Government-owned corporation)	National Nuclear Safety Administration within the Ministry of Environmental Protection	No decision made.	No decision made.
Finland	Nuclear Energy Act (1987) Nuclear Energy Decree (1988) Nuclear Energy Act Amendments (1994, 2003, 2008)	Posiva Oy (Joint waste management company created in 1995 by two utilities, Fortum Power and Heat Oy and Teollisuuden Voima Oyj.)	Radiation and Nuclear Safety Authority (Advises Government on the safety of proposed facilities)	None	Nuclear Waste Management Fund Generators estimate cost of radioactive waste disposal and nuclear power plant decommissioning. They pay annually the difference between Fund target and amount existing in the Fund. Payment can be in securities. Excess payments can be recovered.
France	Research on Radioactive Waste Management Act (1991) Planning Act Concerning the Sustainable Management of Radioactive Materials and Waste (2006) Transparency and Security in the Nuclear Field (2006)	National Agency for Radioactive Waste Management reporting to the Ministries of Environment, Industry, and Research (Government-owned Public Service Agency)	Nuclear Safety Authority	National Review Board (Advises Government and Parliament) Local Information and Oversight Committee (Must be consulted on issues relating to the operation of an underground research laboratory.)	Yes The National Agency for Radioactive Waste Management must estimate costs of designing, constructing, operating, and closing a repository. The waste generators must contribute to a Fund, which is supervised by an independent commission established under the 2006 Planning Act.

Institutional Arrangements

	Regulations and Decrees Applicable to Licensing a Deep Geologic Repository			Formal Legislative/Executive Approvals Required for Developing a Deep Geologic Repository		
	Site-Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site-Selection	Facility Construction and Operation
China	National Nuclear Safety Administration Guidelines on Siting of a Radioactive Waste Geological Repository HAD-406/06 (Radioactive waste-specific)	Decree on Environmental Protection (Generic)	National Nuclear Safety Administration Regulations on the Safety Control for Civilian Nuclear Installations HAF001 Regulations on Radioactive Waste Safety HAF401 (Radioactive waste-specific)	Law of the People's Republic of China on Prevention and Control of Radioactive Pollution (2003)	No decision made.	No decision made.
Finland	Government Decree 736-2008 on the Safety of the Disposal of Nuclear Waste Radiation and Nuclear Safety Authority Long-term Safety of Disposal of SNF YVL 8.4 (Radioactive waste-specific)	Decree on Environmental Impact Assessment Procedures (Generic)	Government Decree 736-2008 on the Safety of the Disposal of Nuclear Waste Radiation and Nuclear Safety Authority Long-term Safety of disposal of SNF YVL 8.4 Operation of the final disposal facility for SNF YVL 8.5 (Radioactive waste-specific)	Nuclear Energy Act (1987, 1994, 2008)	Decision-in-Principle by Government (2000) Confirmation of Decision-in-Principle by Parliament (2001, 2002)	Construction and operating licenses are granted by the Government on the advice of Radiation and Nuclear Safety Authority.
France	Nuclear Safety Authority Safety Guide for Final Disposal of Radioactive Waste In Deep Geologic Formations (Radioactive waste-specific)	Code of Environment Articles L121 and R121-R125 (Generic)	Nuclear Safety Authority Safety Guide for Final Disposal of Radioactive Waste In Deep Geologic Formations (Radioactive waste-specific)	Research on Radioactive Waste Management Act (1991)	Approval of a site near the village of Bure in the Meuse/Haute-Marne region in the Planning Act Concerning the Sustainable Management of Radioactive Materials and Waste (2006).	After a license application is submitted, Parliament will prescribe reversibility conditions that have to be met. Afterward, the Council of State can grant the license.

Institutional Arrangements

	Interactions with Local Jurisdictions			Explicit Adoption of a Staged Decision-Making Process
	Local Veto	Limitations on Local Veto	Benefits to be Provided to Local Community for Accepting a Facility	
China	No decision made.	No decision made.	No decision made.	No decision made.
Finland	Yes, by Municipal Council. The Eurajoki nuclear community approved a positive statement, thereby not vetoing the siting of a HLW/SNF repository.	Veto shall be exercised before the Government makes a Decision-in-Principle on the repository. Veto cannot be overridden.	A benefits package was negotiated between Eurajoki Township and Posiva Oy and Teollisuuden Voima Oyj in 1999. The scale of benefits is minimal, including a loan to construct a new home for the elderly. The former home was renovated and rented to Posiva Oy.	No
France	None, but the local governments in the Meuse/Haute-Marne region volunteered for an underground site-characterization program.	Not applicable	The 2006 Planning Act defines a series of measures to support local development, including a dedicated tax on Basic Nuclear Installations.	Yes

Technical Approaches

	Operating Nuclear Power Plants/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a Deep Geologic Repository	Independent Centralized Interim-Storage Facility Established	Geologic Environments Considered or Investigated for a Repository
China	11 nuclear power plants (8.6 GWe) 16 nuclear power plants are under construction. (16.0 GWe)	Yes A small reprocessing plant located in northwest China is expected to begin operation in 2010.	No decision made.	No	Granite, shale, tuff, mudstone, and diorite
Finland	Four nuclear power plants (2.7 GWe) One nuclear power plant is under construction. (1.6 GWe)	No	No final decision has been made about transportation mode. Readily available options include sea, truck, and rail.	No	Granite, gneiss, granodiorite, and migmatite
France	58 nuclear power plants (63.5 GWe) One nuclear power plant is under construction. (1.6 GWe)	Yes	Meuse/Haute-Marne region is accessible only by truck, but studies are under way to explore alternatives.	No	Argillite and granite

Technical Approaches

	Indigenous Underground Research Laboratories	Status of Site-Selection Process	Long-Term Health and Safety Requirements	Requirements for Retrievability	Requirements for Defense-in-Depth
China	None	Preliminary investigations are under way at the Beishan site (granite) in the Gobi Desert in Gansu Province in Northwest China. Site-Selection is not anticipated before 2020.	No decision made.	No decision made.	No decision made.
Finland	Construction of ONKALO underground rock characterization facility in Eurajoki began in 2004 and is continuing. Experimental work is being conducted during construction. (Migmatite)	Olkilouto, a site at Eurajoki in migmatite, has been approved by Government (2000) and by Parliament (2001). It is being characterized at depth.	For the first several thousand years, dose limit is less than 0.1 mSv/year for normal events. Release limits for selected radionuclides established. Beyond the first several thousand years, impacts can be comparable to those arising from natural radioactive substances but should remain insignificantly low.	The regulatory requirement for retrievablility was eliminated in 2008. However, Posiva is still required under the 2000 Decision-in-Principle to present a plan and cost estimate for retrieving the waste when it submits an application for a construction license.	The barriers should complement each other so that a deficiency in one will not jeopardize long-term safety.
France	Construction of the Meuse/Haute-Marne facility near the village of Bure began in 1999. (Argillite)	The National Agency for Radioactive Waste Management is deciding, in consultation with local communities, where in the transposition zone, a $250 km^2$ area north of Bure, the repository should be sited.	Dose limit is 0.25 mSv/year for normal scenarios. Compliance period is 10^4 years.	The repository must be designed so that it is "reversible" for at least 100 years. Reversibility is a management concept that requires technical retrievability.	Required Safety Guide for Final Disposal of Radioactive Waste In Deep Geologic Formations Chapters 5.1 and 6.1

Technical Approaches

	Methodology for Demonstrating Compliance with Postclosure Standards	Engineered Barrier System		Waste Forms Authorized to be Disposed of in a Deep Geologic Repository	Anticipated Start of Repository Operations
		Design	Importance to Safety Case		
China	No decision made.	No decision made.	No decision made.	HLW	Around 2050
Finland	Compliance is to be demonstrated by means of a deterministic, conservative safety case that addresses both the expected evolutions and unlikely disruptive events affecting long-term safety. The safety case consists of a numerical analysis based on experimental studies and will be complemented by qualitative expert judgment whenever quantitative analyses are not feasible or are too uncertain.	Double-shelled waste package composed of copper (outer) and cast-iron (inner); the annulus between the canister and the rock wall will be filled with highly compacted bentonite.	Very important	Commercial SNF	2020
France	Compliance is shown through the deterministic evaluation of several normal and altered scenarios. In addition, deterministic sensitivity calculations are used to evaluate the impact of uncertainty.	Vitrified waste placed within stainless steel packages.	Minimal	HLW and long-lived intermediate-level waste	2025

Germany, Japan, Republic of Korea

Institutional Arrangements

	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
Germany	Atomic Energy Act (1959) Nuclear Licensing Procedure Ordinance (1977) Federal Mining Act (1980) Waste Disposal Advance Payments Ordinance (1982) Precautionary Radiation Protection Act (1986) Radiation Protection Ordinance (2001)	Federal Office for Radiation Protection within the Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety may make use of "third parties," such as the private German Service Company for the Construction and Operation of Waste Repositories (Government Agency)	Supervisory authority and author of rules and guidelines: Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety Licensing authorities: States (Länder) Ministries under the Atomic Energy Act, State authorities for water use and protection, and competent State mining authorities under the Federal Mining Act	Nuclear Waste Management Commission (Advises the Ministry for the Environment, Nature Conservation, and Nuclear Safety)	None, but research and development costs for a repository are recovered from the waste generators.
Japan	Final Disposal of Specific Radioactive Wastes Act (2000, 2007) Reactor Regulation Law (1957, amended in 2007 to establish a safety regulation system for the disposal of HLW and transuranic waste)	Nuclear Waste Management Organization (Private nonprofit organization established by the owners of nuclear power plants)	Nuclear and Industrial Safety Agency, a unit within the Ministry of Economy, Trade, and Industry	None, although the Nuclear Safety Commission advises the Nuclear and Industrial Safety Agency.	Yes. With respect to HLW, each year, the Ministry of Economy, Trade, and Industry notifies nuclear power plant owners how much they need to deposit in the High-Level Waste Fund. Yes. With respect to Transuranic Waste, the Ministry of Economy, Trade, and Industry notifies the owners of reprocessing plants and mixed-oxide fuel fabrication plants how much they need to deposit in the Transuranic Waste fund.
Republic of Korea	Atomic Energy Act (1988) Enforcement Decree of the Atomic Energy Act (1988) Radioactive Waste Management Law (2008)	Korea Radioactive Waste Management Organization (Government Agency)	Ministry of Education, Science, and Technology (Advised by Korea Institute of Nuclear Safety and Nuclear Safety Commission)	None	"Polluter pays" principle adopted in Atomic Energy Act Radioactive Waste Management Fund No decision made on implementation except that the generator pays only after waste is accepted for centralized storage or disposal.

Institutional Arrangements

	Regulations and Decrees Applicable to Licensing a Deep Geologic Repository			Formal Legislative/Executive Approvals Required for Developing a Deep Geologic Repository		
	Site-Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site-Selection	Facility Construction and Operation
Germany	No decision made.	Environmental Impact Assessment Act (Generic)	Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste (Radioactive waste-specific)	Atomic Energy Act (1959)	No decision made.	Plan Approval by the State where the site is located, subject to supervision by the Federal Government.
Japan	None The Nuclear Safety Commission has published guidelines (not regulations) that the Nuclear Waste Management Organization must follow.	No decision made.	Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety Rules for Category 1 Waste Disposal for Nuclear Fuel Material (Radioactive waste-specific)	Final Disposal of Specific Radioactive Wastes Act (2000, revised in 2007)	With the consent of the Cabinet, the Minister of Economy, Trade, and Industry must give approval.	With consent of the Cabinet, the Minister of Economy, Trade, and Industry must give approval.
Republic of Korea	Ministry of Education, Science, and Technology Siting Criteria for Spent Fuel Interim Storage Facilities Notice Number 2008-58 No decision made for HLW/SNF repository. (Radioactive waste-specific)	Ministry of Education, Science, and Technology Regulation on the Environmental Radiation Survey and Impact Analysis in the Vicinity of Nuclear Facilities Notice Number 2008-28 (Radioactive waste-specific)	Ministry of Education, Science, and Technology Criteria for Radioactive Dose Notice Number 1998-12 and 2005-17 promulgated by the Ministry of Education, Science, and Technology's predecessor body, the Ministry of Science and Technology (Radioactive waste-specific)	Atomic Energy Act (1988)	No decision made.	No decision made.

Institutional Arrangements

	Interactions with Local Jurisdictions			Explicit Adoption of a Staged Decision-Making Process
	Local Veto	Limitations on Local Veto	Benefits to be Provided to Local Community for Accepting a Facility	
Germany	No decision made.	No decision made.	No decision made.	"Stepwise optimization" is mandated under the Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste.
Japan	The Mayor of host community and the Prefectual Governor must agree to participate in the siting process.	None	If a local community agrees to be included in a literature survey of potential sites, it and its neighboring communities will receive up to $18 million. If the community subsequently allows surface-based site investigations, it and its neighboring communities will receive up to $65 million.	Yes
Republic of Korea	No decision made for HLW/SNF repository. A volunteer nuclear community (Kyongju/Gyeonju) agreed in a referendum to host a low- and intermediate-level waste disposal site.	No decision made on HLW/SNF repository. None for a low- and intermediate-level waste disposal site.	No decision made for HLW/SNF repository. $300 million provided local community for low- and intermediate-level waste disposal site; in addition, the community will receive $10 million per year after the facility begins operation. Other benefits are possible.	No decision made for HLW/SNF disposal. A staged decision-making process for low- and intermediate-level waste disposal is in place.

Technical Approaches

	Operating Nuclear Power Plants/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a Deep Geologic Repository	Independent Centralized Interim-Storage Facility Established	Geologic Environments Considered or Investigated for a Repository
Germany	17 nuclear power plants (20.3 GWe)	Before 1994, commercial SNF had to be reprocessed. Between January 1, 1994, and June 30, 2005, nuclear power plant owners had the option of reprocessing their commercial SNF. Under amendments to the Atomic Energy Act in 2002, transport of commercial SNF to reprocessing plants after July 1, 2005, was prohibited. Most of the reprocessing of German commercial SNF was done at La Hague, although smaller amounts were reprocessed at Sellafield, EUROCHEMIC, and Karlsruhe.	No decision made.	Facilities at Gorleben and Ahaus store small amounts of commercial SNF. HLW is stored at Gorleben. Under the amendments to the Atomic Energy Act in 2002, commercial SNF has to be stored at nuclear power plants.	Salt
Japan	53 nuclear power plants (46.2 GWe) Three nuclear power plants are under construction. (3.7 GWe)	Yes. Commercial SNF from Japan has been reprocessed in France and the United Kingdom. In addition, reprocessing takes place in a small facility at Tokai and, pending the results of pre-service testing, will take place at a large facility at Rokkasho Village.	No decision made.	No	Granite and sedimentary rock
Republic of Korea	20 nuclear power plants (17.7 GWe) Six nuclear power plants are under construction. (6.7 GWe)	All SNF used in light-water reactors is of U.S. origin. The U.S. has refused to permit the reprocessing of that fuel.	No decision made.	Envisioned, but no schedule for beginning to site such a facility has been established.	Granite

Technical Approaches

	Indigenous Underground Research Laboratories	Status of Site-Selection Process	Long-Term Health and Safety Requirements	Requirements for Retrievability	Requirements for Defense-in-Depth
Germany	Underground exploration of the Gorleben site was launched in 1986 but was suspended in 2000. (Salt)	The Site-Selection process, which focused on the Gorleben site, was suspended in 2000 for no longer than 10 years. The suspension was agreed to by the Government and the nuclear power plant owners. The Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety published a concept for the site-selection process in 2006.	The additional risk of serious health damage must be less than 10^{4}/lifetime for probable scenarios.* The additional risk of serious health damage must be less than 10^{-3}/lifetime for less probable scenarios.* Compliance period is 10^{6} years. * lifetime means 100 years for humans	Retrievability of HLW and SNF need not be provided in the disposal concept. However, shielding of the ionizing radiation has to be guaranteed so that the waste will be manageable for possible retrieval for a period of 500 years after repository closure, taking into account probable developments.	The safety after repository closure has to be secured through a robust and graded barrier system. The functions of this system should be fulfilled passively and without any maintenance. In addition, the functionality should be maintained in a sufficient way even for the case that individual barriers will not provide their full effectiveness.
Japan	Tono (granite) Two laboratories are under construction: Mizunami (granite) and Horonobe (sedimentary rock).	The Nuclear Waste Management Organization has adopted a transparent and voluntary approach for finding candidate sites. One town (Toyo-cho) initially agreed to participate but then withdrew. The national government may take a more proactive role in identifying sites in the future.	No decision made.	No decision made.	No decision made.
Republic of Korea	Korea Underground Research Tunnel at shallow depth (Granite)	No schedule for beginning to site a HLW/SNF repository has been established. A volunteer nuclear community (Kyongju/Gyeonju) has agreed to host a low- and intermediate-level waste disposal site.	No decision made for HLW/SNF disposal. For low- and intermediate-level waste disposal, 0.1 mSv/year for normal events; risk limit of 10^{-6}/year for probabilistic disruptive events; 1 mSv/year for human intrusion.	No decision made, but, in the conceptual-level Reference Design, waste packages had to be retrievable for an indeterminate period.	Safety philosophy includes defense-in-depth and some degree of redundancy in multi-barrier function.

Technical Approaches

	Methodology for Demonstrating Compliance with Postclosure Standards	Engineered Barrier System		Waste Forms Authorized to be Disposed of in a Deep Geologic Repository	Anticipated Start of Repository Operations
		Design	Importance to Safety Case		
Germany	Deterministic calculations have to be carried out on the basis of modeling as realistically as possible, using, for example, median values as input parameters.	No decision made.	No decision made.	HLW, commercial SNF, and heat-generating intermediate-level waste	No decision made.
Japan	No decision made. A generic performance assessment (H12) has been carried out (1999): • No specific host rock modeled. • A range of scenarios evaluated deterministically. • Sensitivity calculations addressed uncertainty. • Calculations carried out to at least 10^8 years. • Peak dose was less than 0.1mSv/year.	No decision made. In the H12 performance assessment, vitrified waste in stainless steel containers is disposed of in a carbon steel overpack that is surrounded by bentonite.	No decision made. In the H12 performance assessment, all packages were assumed to fail at 10^3 years.	HLW	No decision made.
Republic of Korea	No decision made. A quantitative approach for up to 10,000 years is envisioned, with qualitative assessments carried out for subsequent periods.	No decision made. A conceptual-level Reference Design was developed in the late 1990's. In the Reference Design, options considered for the canisters were high-nickel alloys, stainless steel, and copper. The canisters would be surrounded by bentonite.	In the conceptual-level Reference Design, the engineered barrier system was very important.	Commercial SNF	No decision made.

Spain, Sweden, Switzerland

Institutional Arrangements

	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
Spain	Nuclear Energy Act, Law 25/1964, modified by Law 24/2005 Act Creating the Nuclear Safety Council, Law 15/1980, modified by Law 33/2007	Spanish National Company for Radioactive Waste (Government-owned Corporation)	Nuclear Safety Council The Ministry of Industry, Tourism, and Trade legally makes the final decision but cannot overturn the Nuclear Safety Council's report if it is negative or conditional.	None	Nuclear Decommissioning Fund paid into by the waste producers. (Covers both decommissioning of nuclear power plants and radioactive waste management)
Sweden	Act on Nuclear Activities (1984) Radiation Protection Act (1988) Environmental Code (1998)	Swedish Nuclear Fuel and Waste Management Company (Private corporation formed by the owners of nuclear power plants)	Radiation Safety Authority, within the Ministry of the Environment, was established in 2008 by merging the Radiation Protection Institute and the Nuclear Power Inspectorate.	National Council for Nuclear Waste (Advises the Ministry of the Environment)	Nuclear Waste Fund Owners of nuclear power plants pay a fee based on the estimated costs of disposing of SNF. The fee varies from year to year and varies as well from plant to plant. Owners provide a guarantee to cover the difference between money paid into the Fund and the total estimated cost of disposal.
Switzerland	Atomic Energy Act (1959, modified to the Nuclear Energy Act in 2003) Environmental Protection Act (1983) Radiological Protection Act (1991) Radiological Protection Ordinance (1994) Ordinance on the Collection of Radioactive Waste (2002) Nuclear Energy Ordinance (2004) Nuclear Safety Inspectorate Act (2007) Ordinance on Decommissioning and Waste Management Fund (2008)	National Cooperative for the Disposal of Radioactive Waste (The National Cooperative for the Disposal of Radioactive Waste is a public/private consortium of radioactive waste producers, including all the owners of nuclear power plants and the Federal State.)	Department of Environment, Transport, Energy, and Communications, advised by the Federal Nuclear Safety Inspectorate and the Federal Nuclear Safety Commission	Nuclear Safety Commission (Advises Federal Council, Federal Department of Environment, Transport, Energy, and Communications, and the Federal Nuclear Safety Inspectorate)	Radioactive Waste Disposal Fund for Nuclear Installations Consumers of nuclear-generated electricity pay into the Fund a surcharge for each kilowatt-hour produced. Current expenses incurred by the National Cooperative for the Disposal of Radioactive Waste are paid for annually by the nuclear power plant owners.

Institutional Arrangements

	Regulations and Decrees Applicable to Licensing a Deep Geologic Repository			Formal Legislative/Executive Approvals Required for Developing a Deep Geologic Repository		
	Site-Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site-Selection	Facility Construction and Operation
Spain	Royal Decree 775/2006 established process for siting the Centralized Temporary Storage facility. No decision has been made for a HLW/SNF repository.	Royal Decree 1/2008	Royal Decree 1836/1999, modified by Royal Decree 35/2008 Nuclear Safety Council Regulation on Nuclear and Radioactive Facilities	No decision made.	No decision made.	No decision made.
Sweden	None	The Environmental Impact Assessment process is consistent with Directives from the European Union.	Regulations promulgated by the Radiation Protection Institute and the Nuclear Power Inspectorate have been adopted by the Radiation Safety Authority. SSIFS 1998 :1 SSIFS 2005:5 SKIFS 1998:1 SKIFS 2002 :1 SKIFS 2004: 1	In 1983, the Government decided that the KBS-3 approach formed an acceptable basis for the Swedish Nuclear Fuel and Waste Management Company to use in its plans for developing a repository.	In 2001, the Government approved a proposal by the Swedish Nuclear Fuel and Waste Management Company to investigate sites in Östhammar and Oskarshamn to determine whether they were suitable for developing a repository.	The Radiation Safety Authority will review a license application, scheduled to be submitted in 2010, and advise the Government on its acceptability. Concurrently, an Environmental Court will rule on the application. Taking the Radiation Safety Authority's advice and the Environmental Court's ruling into account, the Government will decide whether to approve the license application. There also may be a non-binding vote of Parliament.
Switzerland	Federal Council in 2008 approved the concept of the Sectoral Plan (Sachplan).	Federal Office for the Environment reviews Environmental Impact Assessments.	Federal Nuclear Safety Inspectorate Protection Objectives for the Disposal of Radioactive Waste Guideline G03 (2009) replaces HSK-R-21 (1993).	Nuclear Energy Acts of 1959 and 2003	General License granted by Federal Council and approved by Parliament. General License may be challenged in a national Facultative Referendum.	Construction and operating licenses granted by Federal Department of Environment, Transport, Energy, and Communications.

Institutional Arrangements

	Interactions with Local Jurisdictions			Explicit Adoption of a Staged Decision-Making Process
	Local Veto	Limitations on Local Veto	Benefits to be Provided to Local Community for Accepting a Facility	
Spain	No decision made for a HLW/SNF repository. The process established for siting the Centralized Temporary Storage facility requires voluntary participation by local communities.	No decision made for a HLW/SNF repository.	No decision made for a HLW/SNF repository.	No decision made for a HLW/SNF repository.
Sweden	Local community can veto the choice of a site.	National override of veto only if there is no alternative location for the repository in a community more willing to accept it.	Oskarshamn, the community not selected, will receive, in an added-value package, $180 million for participating in the siting process. Östhammar, the community selected, will receive $60 million.	A license for a geological repository for SNF will be granted in two steps. The first step involves the full licensing of a facility. After several years of trial operation, regular operation will begin.
Switzerland	None, although informal participation and formal consultations are required at all stages of the Sectoral Plan.	Not applicable	No decision made. To be decided in Stage 3 of the Sectoral Plan.	The Sectoral Plan contains three stages.

Technical Approaches

	Operating Nuclear Power Plants/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a Deep Geologic Repository	Independent Centralized Interim-Storage Facility Established	Geologic Environments Considered or Investigated for a Repository
Spain	Eight nuclear power plants (7.4 GWe)	Some commercial SNF from the Vandellós I plant was reprocessed at La Hague. Additional commercial SNF from the Santa María de Garoña plant was reprocessed at Sellafield. Current national policy does not contemplate any additional reprocessing.	No decision made.	A process was initiated in 2006 to site a Centralized Temporary Storage facility. No site has been chosen.	Granite, clay, and salt No geological environments are currently under consideration.
Sweden	10 nuclear power plants (9.1 GWe)	No Although small amounts of commercial SNF have been reprocessed in France and the United Kingdom, no vitrified waste was returned to Sweden.	Waste can be moved to the Östhammar site by a specially designed ship, the Sigyn.	Yes, the CLAB facility in Oskarshamn was commissioned in 1985.	Granite
Switzerland	Five nuclear power plants (3.2 GWe)	Commercial SNF has been reprocessed in France and the United Kingdom. Some HLW has been returned to Switzerland. Some extracted plutonium and some extracted uranium has been used to make MOX assemblies. Discharged SNF not covered by reprocessing contracts in place in 2002 may not be reprocessed until at least 2016.	No decision made.	A Central Storage Facility (ZWILAG) in Würenlingen, near the Beznau Nuclear Power Plant, holds HLW and SNF.	Clay and granite

Technical Approaches

	Indigenous Underground Research Laboratories	Status of Site-Selection Process	Long-Term Health and Safety Requirements	Requirements for Retrievability	Requirements for Defense-in-Depth
Spain	None	No decision made.	For low- and intermediate-level waste disposal, dose constraint is 0.1 mSv/year for high-probability scenarios; risk limit of 10^{-6}/year is for lower probability scenarios. No decision made for HLW/SNF repository.	No decision made.	No decision made.
Sweden	Construction of the Äspö laboratory in Oskarshamn began in 1990 and was completed in 1995. (Granite)	A site in the municipality of Östhammar was selected in 2009.	Risk limit of 10^{-6}/year for 10^{5} years. The risk analysis should be carried out for no longer than 10^{6} years.	None	The barrier system shall comprise several barriers so that, as far as possible, the necessary safety is maintained in spite of a failure in one barrier.
Switzerland	Mont Terri near Saint Ursanne (clay) and Grimsel in the Berne Canton (granite)	Sectoral Plan is at Stage 1, in which potential regions are examined based on their geological characteristics. The National Cooperative for the Disposal of Radioactive Waste has recommended three regions for further exploration. All are in Opalinus clay and are in northern Switzerland. The proposals are under review by Department of Environment, Transport, Energy, and Communications, advised by the Federal Nuclear Safety Inspectorate, the Federal Nuclear Safety Commission, and the Commission for Nuclear Waste Disposal.	Dose constraint relevant to high-probability scenarios 0.1 mSv/year; risk target of 10^{-6}/year for lower-probability scenarios. Complete containment is required for 1,000 years. The protection of man and the environment is "permanent." However, as a practical matter, safety assessments will be carried out for 10^{7} years.	The retrievability of HLW has to be considered when designing the repository. The technical feasibility of retrieving the waste has to be demonstrated in experiments on a 1:1 scale before the repository starts operation.	The regulations require that the long-term safety of a repository shall be ensured by a system of multiple passive safety barriers. Although some "redundancy to ensure insensitivity to uncertainties" is required, the regulations do not specify any particular level.

	Methodology for Demonstrating Compliance with Postclosure Standards	Engineered Barrier System		Waste Forms Authorized to be Disposed of in a Deep Geologic Repository	Anticipated Start of Repository Operations
		Design	Importance to Safety Case		
Spain	No decision made.	No decision made.	No decision made.	No decision made.	No decision made.
Sweden	The regulations do not prescribe a specific methodology for demonstrating compliance. Both deterministic and probabilistic approaches can be used. Three types of scenarios are to be evaluated: • Main scenario—based on the probable evolution of the external conditions using realistic or pessimistic assumptions. • Less probable scenarios—prepared for the evaluation of uncertainties. Include variations on the main scenario with alternative sequences of event. • Residual scenarios—include sequences of events and conditions that illustrate the significance of individual barriers and barrier functions.	Commercial SNF is placed in a copper canister that has a cast-iron insert for support. The canister is surrounded by bentonite clay.	Very important	Commercial SNF	2023
Switzerland	No decision made. In a study, Project Entsorgungsnachweis, evaluating the feasibility of the Opalinus clay disposal concept, a deterministic performance assessment of a "Reference Scenario" was carried out. In addition, five other ("what-if") scenarios, often containing subscenarios, were evaluated to explore the effects of uncertainty. Complementing the deterministic calculations were some probabilistic analyses.	The disposal concept evaluated in Project Entsorgungsnachweis envisions canisters for HLW and commercial SNF made out of cast iron. HLW is contained in a stainless steel flask inside the canister. The canisters are surrounded by bentonite clay.	Relatively unimportant compared to the Opalinus clay.	HLW	Not earlier than 2040

United Kingdom

Institutional Arrangements

	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
United Kingdom	Nuclear Installations Act (1965) Radioactive Substances Act (1993)	Nuclear Decommissioning Authority Radioactive Waste Management Directorate (Non-Departmental Public Body under the responsibility of the Department of Energy and Climate Change; for some aspects of its functions, it is also responsible to Scottish Ministers.)	Environment Agency (for England and Wales) Scottish Environment Agency Northern Ireland Department of Environment Health and Safety Executive Department for Transport	Committee on Radioactive Waste Management (Advises Government and ministers of the devolved administrations of Scotland, Wales, and Northern Ireland)	None Government will pay the costs of managing legacy waste. The policy of the Government is that owners and operators of new nuclear power plants set aside funds to cover their full share of waste management and disposal costs.

Institutional Arrangements

	Regulations and Decrees Applicable to Licensing a Deep Geologic Repository			Formal Legislative/Executive Approvals Required for Developing a Deep Geologic Repository		
	Site-Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site-Selection	Facility Construction and Operation
United Kingdom	None	European Union Environmental Impact Assessment Act transposed in the United Kingdom by the Planning (Environmental Impact Assessment) Regulations	Environment Agency Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance of Requirements for Authorisation (2009)	Department of Environment, Food, and Rural Affairs Response to the Report and Recommendations of the Committee on Radioactive Waste Management (2006) Department of Environment, Food, and Rural Affairs White Paper on Managing Radioactive Waste Safely (2008)	Government must ultimately approve the site. However, under the voluntarism and partnership approach, at each stage of site-selection the process, the decision-making body for the local community will decide whether to proceed with the next step.	After authorization by the Environment Agency, planning permission/ development consent, and licensing by the Health and Safety Executive, no further action is required.

Institutional Arrangements

	Interactions with Local Jurisdictions			Explicit Adoption of a Staged Decision-Making Process
	Local Veto	Limitations on Local Veto	Benefits to be Provided to Local Community for Accepting a Facility	
United Kingdom	The Government has committed to siting a repository only in a "willing" community.	The right of the community to withdraw from the process can be exercised until the point that underground construction and operations begin.	No decision made. The Government believes that any benefits package should be developed among the communities, Government, and the Nuclear Decommissioning Authority, taking account of local needs, affordability, and the value of money.	The Managing Radioactive Waste Safely program contains six stages.

Technical Approaches

	Operating Nuclear Power Plants/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a Deep Geological Repository	Independent Centralized Interim-Storage Facility Established	Geologic Environments Considered or Investigated for a Repository
United Kingdom	19 nuclear power plants (11.0 GWe)	Yes, at Sellafield. The Government's position is that the decision to reprocess in the future should be left to the commercial judgment of the owners of the SNF. SNF is not classified as waste.	No decision made.	No	No decision made.

Technical Approaches

	Indigenous Underground Research Laboratories	Status of Site-Selection Process	Long-Term Health and Safety Requirements	Requirements for Retrievability	Requirements for Defense-in-Depth
United Kingdom	None	The Government has solicited expressions of interest from local governments and communities. So far, there have been three expressions of interest, from the Copeland Borough Council, from the Allendale Borough Council, and from the Cumbria Borough Council. All of these localities are close to the Sellafield site.	According to regulatory guidances, radiological risk from a disposal facility to a person representative of those at greatest risk should be consistent with a risk limit level of 10^{-6}/year.	No decision made, but planning and guidance require that the option of retrievability not be foreclosed.	A requirement of regulatory guidance.

Technical Approaches

	Methodology for Demonstrating Compliance with Postclosure Standards	Engineered Barrier System		Waste Forms Authorized to be Disposed of in a Deep Geologic Repository	Anticipated Start of Repository Operations
		Design	Importance to Safety Case		
United Kingdom	No decision made.	No decision made.	No decision made.	HLW, commercial SNF, intermediate-level waste, and low-level waste not suitable for near-surface disposal. Uranium and plutonium if these elements are declared to be waste.	No decision made.

GLOSSARY†

analysis, deterministic A simulation of the behavior of a system utilizing a single-valued set of parameters, events, and features. *See* also **analysis, probabilistic.**

analysis, 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.

analysis, risk An analysis of possible events and their probabilities of occurrence together with their potential consequences.

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, 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. This differs from safety assessment in that it can be applied to parts of a facility and does not necessarily require assessment of radiological impacts.

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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).

assessment, safety An analysis for evaluating the performance of an overall system and its impact where the performance measure is radiological impact or some other global measure of impact on safety.

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.

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.

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.**

decommissioning 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 constraint 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 cycle, once-through Refers to the fuel cycle option where spent fuel is disposed of directly after use and is not reprocessed. *See* also **direct disposal.**

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

geologic barrier *See* **barrier.**

geologic disposal *See* **repository, geologic.**

geologic repository *See* **repository, geologic.**

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

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

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

heat-generating waste *See* **waste, heat generating.**

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

host medium/rock *See* **rock, host.**

intermediate-level waste *See* **waste, low- and intermediate-level.**

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

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

license An authorization issued by the regulatory body granting permission to perform specified activities related to a facility or an activity. 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 exceed the time during which active institutional control can be expected to last.

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.**

once-through fuel cycle *See* **fuel cycle, once through.**

overpack A secondary (or additional) outer container for one or more waste packages, used for handling, transport, storage, or disposal.

package, spent fuel A vessel containing conditioned spent fuel in a form suitable for transport, storage, and disposal.

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.**

probabilistic analysis *See* **analysis, probabilistic.**

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 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.

risk limit The probability of a person living in the vicinity of a repository suffering genetic or serious health damage, including cancer, during the course of his or her lifetime as a result of radioactive material released from the isolating rock zone.

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 assessment *See* **assessment, safety.**

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 confirmation The final stage of the siting process for a repository. Site confirmation is based on detailed investigations of the preferred site that provide site-specific information needed for safety assessment.

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; site confirmation.

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.

spent fuel package *See* **package, spent fuel.**

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

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

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

tuff A rock composed of compacted volcanic ash.

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

vitrification The process of incorporating materials into a glass or glass-like form. Vitrification is commonly applied to the solidification of liquid high-level radioactive waste from the reprocessing of spent nuclear fuel. *See* also **glass.**

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 30 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.**

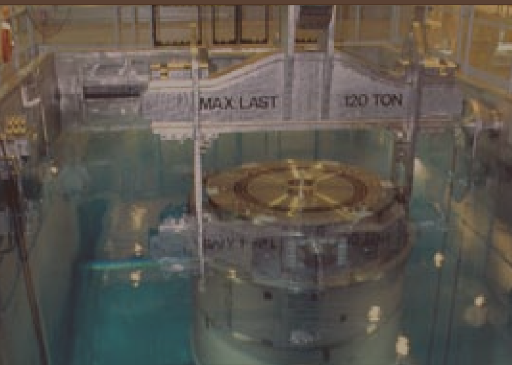
waste disposal *See* **disposal.**

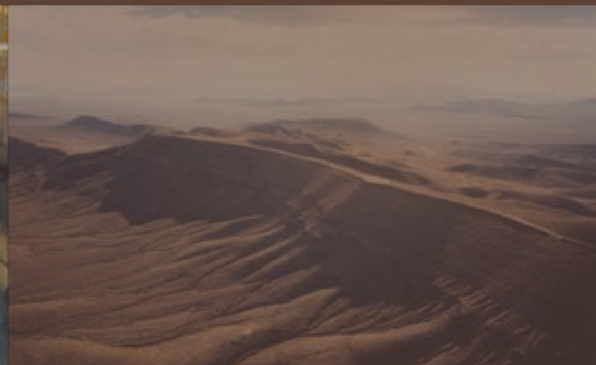
waste disposal system Refers to the disposal environment as a whole, including the geological surroundings, the engineering system of a repository (e.g., barriers), and the waste packages.

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.**





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