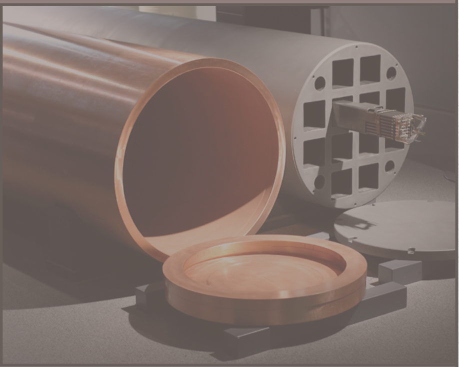

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update

A Report to Congress
and the Secretary of Energy

July 2022

UNITED STATES
Nuclear Waste Technical Review Board

U.S. Nuclear Waste Technical Review Board

Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update

A Report to Congress and the Secretary of Energy

July 2022

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

July 2022

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

The Honorable Patrick J. Leahy
President Pro Tempore
United States Senate
Washington, DC 20510

The Honorable Jennifer Granholm
Secretary
U.S. Department of Energy
Washington, DC 20585

Dear Speaker Pelosi, Senator Leahy, and Secretary Granholm:

The U.S. Nuclear Waste Technical Review Board submits the enclosed report, *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: 2022 Update,* in accordance with provisions of the 1987 Nuclear Waste Policy Amendments Act (NWPAA) (Public Law 100-203), which directs the Board to report its findings and recommendations to Congress and the Secretary of Energy. 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 implementing the Nuclear Waste Policy Act.

The enclosed report is an update of a survey report issued by the Board in 2009, in which the Board described 30 institutional and technical attributes of nuclear waste management programs in 13 countries. The original Survey, a 2016 Update Report, and this Update Report make no judgements about any of the programs. Rather, the reports focus on experiences in the United States and other countries that will provide useful technical and scientific information for decision-makers in Congress and the Administration on different approaches to managing and disposing spent nuclear fuel and high-level radioactive waste.

The Board looks forward to continuing its independent evaluation of Department of Energy activities related to spent nuclear fuel and high-level radioactive waste management and disposal and to providing critical technical and scientific information to Congress and the Secretary.

Sincerely,

{signed}

Jean M. Bahr
Chair

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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).

Preface

In October 2009, the U.S. Nuclear Waste Technical Review Board (Board or NWTRB) published *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*.[1] For each of the 13 national programs studied, the report catalogued 15 institutional arrangements that had been set in place and 15 technical approaches that had been taken to design repository systems for the long-term management of high-activity radioactive waste. (If no decision had been made, either with respect to an institutional arrangement or to a technical approach, this was also noted.) The information gathered was displayed in a set of Detailed Tables. An update to the 2009 report was published in 2016.[2] Since 2016, changes in national waste management programs have taken place in many of the 13 countries. To remain current, the Board, therefore, decided to publish an update to the 2016 report.

One of the most important changes in the United States since 2009 is the decision by the Obama Administration to suspend the effort to develop a deep geologic repository at Yucca Mountain in Nevada. In the wake of a 2013 federal court decision, the U.S. Nuclear Regulatory Commission (NRC) restarted its review of the 2008 license application submitted by the U.S. Department of Energy (DOE) and published the Safety Evaluation Report in 2015 (DOE 2017).[3] NRC staff found that DOE's license application for construction authorization met the regulatory requirements for the proposed repository except for the requirements regarding land and water rights. In 2016, NRC staff developed a supplement to DOE's Environmental Impact Statement to address groundwater impacts previously identified by NRC staff as requiring additional analysis. The adjudication of the license application is currently suspended.[4] Most of the information for the United States included in this report applies whether or not a repository is developed at Yucca Mountain. When the information relates specifically to the Yucca Mountain site, however, this circumstance is noted.

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[1]NWTRB. October 2009. *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-sept-09.pdf?sfvrsn=7. (Accessed January 20, 2022.)

[2]NWTRB. 2016. *Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: Update*. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/survey_report_2016.pdf?sfvrsn=6. (Accessed January 20, 2022.)

[3]DOE. 2017. *United States of America - Sixth National Report for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. Washington, DC. https://www.iaea.org/sites/default/files/10-20-176thusnationalreportfinal.pdf. (Accessed January 20, 2022.)

[4]DOE. 2020. *United States of America - National Report for the Seventh Review Meeting of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management*. Washington, DC. https://www.energy.gov/sites/default/files/2020/10/f80/7th-JC-RM-United-States-NR-Final-Oct-2020.pdf. (Accessed January 20, 2022.)

Overview

The creation of high-activity, long-lived radioactive waste is an inevitable consequence of irradiating nuclear fuel for generating electricity in nuclear power plants and 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 ultimate disposition of those wastes was not widely considered 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 seriously damage the environment.

Those efforts have benefitted from increasingly fruitful international cooperation and coordination. For instance, the International Atomic Energy Agency (IAEA), 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 accepted by 88 parties,[5] including 32 countries[6] with operational nuclear power plants. Under the auspices of its Radioactive Waste Management Committee, the Nuclear Energy Agency (NEA), part of the Organization for Economic Co-operation and Development, has established subsidiary bodies[7] that sponsor multinational exchanges among 34 industrial democracies.[8]

Today, there is strong international consensus that a deep geologic repository (DGR) used to dispose of high-activity, long-lived radioactive waste "provides a unique level and duration of protection"[9] of public health and safety and the environment. Such a system "takes advantage of the capabilities of both the

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[5]IAEA. 2022. "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management." https://www-legacy.iaea.org/Publications/Documents/Conventions/jointconv_status.pdf. (Accessed May 23, 2022.)

[6]IAEA. 2022. "In-Operation & Long-Term Shutdown." Accessed February 11, 2022. https://pris.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx.

[7]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.

[8]NEA. "Who we are." Accessed January 20, 2022. https://www.oecd-nea.org/jcms/pl_36846.

[9]NEA Radioactive Waste Management Committee. 2008. "Background Information on Key Points." *In Moving Forward with Geological Disposal of Radioactive Waste: An NEA RWMC Collective Statement,* 7. Paris: Organization for Economic Co-operation and Development. https://www.oecd-nea.org/jcms/pl_18566/moving-forward-with-geological-disposal-of-radioactive-waste-an-nea-rwmc-collective-statement?details=true. (Accessed February 17, 2022.)

local geology and the engineered materials to 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 DGR 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 DGR is operating today: the Waste Isolation Pilot Plant (WIPP) in New Mexico. Transuranic waste from the U.S. nuclear weapons production program and other specially designated waste streams 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.[10] The report is not intended to provide a comprehensive and exhaustive survey of waste management programs in all countries that now operate nuclear power plants. Instead, the report examines programs in 13 selected countries that account for 80 percent[11] of worldwide nuclear power-generating capacity. These countries illustrate the broad range of options and considerations that structure national programs. Information on all of these efforts is readily available. 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 again update this survey and, at that time, may include additional national programs.

For each of the 13 national waste-management programs, the Board gathered detailed information on 30 program attributes. Some of the attributes address the programs' legal and institutional arrangements; others describe technical attributes. (A definition of these attributes can be found starting on page 14.) These data are presented in a series of Detailed Tables. The rest of this section highlights the following program attributes:[12]

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

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

[11] Calculated based on information available in the IAEA Power Reactor Information System (PRIS) database: https://pris.iaea.org/PRIS/WorldStatistics/OperationalReactorsByCountry.aspx. (Accessed February 10, 2022.)

[12] Information contained in Overview section tables, as well as in the Detailed Tables, uses terminology provided by experts from each country. Space limitations sometimes prevented expanding on the information provided.

Context

Commercial and defense spent nuclear fuel (SNF), high-level radioactive waste (HLW), long-lived, heat-generating waste, and wastes from research and isotope production reactors are all potential candidates for disposal in a DGR. But the magnitude of the task of disposal of these wastes in a DGR is best approximated by the capacity of a country's commercial nuclear power plants because commercial SNF typically makes up the vast majority of these materials by volume.

Table 1 provides information related to nuclear-generated electricity for the 13 countries considered in the survey. These countries vary significantly in terms of nuclear power-generating capacity. Belgium, Finland, Germany, Spain, and Switzerland have only a few operating nuclear reactors;[13] France, Japan, and the United States have a substantial number. Further, the countries' dependence on nuclear power ranges from a small percentage of national electricity production to a large majority of it.

In some nations, commitments have been made to construct many new reactors, while in others, 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	Nuclear Reactors in Operation	Generating Capacity (Gigawatts)	Percentage of Total Electricity Production (in 2020)
United States	93	95.5	19.7
Belgium	7	5.9	39.1
Canada	19	13.6	14.6
China	54	50.7	4.9
Finland	4	2.8	33.9
France	56	61.3	70.6
Germany	3	4.1	11.3
Japan	33	31.7	5.1
Republic of Korea	24	23.1	29.6
Spain	7	7.1	22.2
Sweden	6	6.9	29.8
Switzerland	4	3	32.9
United Kingdom	11	6.8	14.5

* Source: Power Reactor Information System database. https://pris.iaea.org/pris/ (Accessed on February 2, 2022).

[13] IAEA. 2022. "Power Reactor Information System." Accessed January 20, 2022. https://pris.iaea.org/pris/.

Table 2

ORGANIZATIONAL FORM OF THE IMPLEMENTER		
COUNTRY	**IMPLEMENTING ORGANIZATION**	**ORGANIZATIONAL FORM**
United States	U.S. Department of Energy	Government agency
Belgium	National Agency for Radioactive Waste and Enriched Fissile Materials	Government agency
Canada	Nuclear Waste Management Organization	Private not-for-profit organization formed by the nuclear electricity producers
China	China Atomic Energy Authority and China National Nuclear Corporation	Government-owned corporation
Finland	Posiva Oy	Joint waste management company created by owners of nuclear power plants
France	National Agency for Radioactive Waste Management	Government-funded industrial and commercial institution
Germany	Federal Company for Radioactive Waste Disposal	Government-owned corporation
Japan	Nuclear Waste Management Organization of Japan	Private non-profit organization established by the owners of nuclear power plants
Republic of Korea	Korea Radioactive Waste Agency	Government agency
Spain	Spanish Radioactive Waste Management Agency	Public, non-profit organization
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 all the owners of nuclear power plants and the Federal Government
United Kingdom	Nuclear Waste Services	A wholly owned subsidiary of the Nuclear Decommissioning Authority, which is a public sector organization

Organizational Form of the Implementer

The implementer is the entity responsible for siting, construction, and operation of a DGR. The various implementers and their organizational form for the 13 countries considered in this survey are summarized in Table 2. Among countries actively considering the very long-term management of radioactive waste, broad consensus is that establishing health, safety, and environmental standards for disposal and deciding whether a DGR should be sited, constructed, or operated are intrinsic governmental functions to be carried out by an independent regulator.[14] There is considerably less agreement on the most appropriate organizational form for the implementer. 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.[15] 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 or public corporations or organizations, government-owned or government-funded organizations, and public-private partnerships.

[14] 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, Organization for Economic Co-operation and Development (OECD), Paris, 2007.

[15] *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/ ADVISORY BODY	ROLE
United States	U.S. Nuclear Waste Technical Review Board	Advises Congress and Secretary of Energy
Belgium	None	
Canada	Advisory Council, Adaptive Phase Management Geoscientific Review Group, and Council of Elders and Youth	Advises the implementer
	Independent Advisory Group	Advises the regulator
China	No decision has been made.	
Finland	None	
France	National Review Board	Advises the implementer, Government, and Parliament
Germany	Nuclear Waste Management Commission	Advises Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
	National Citizens' Oversight Committee	Supports site-selection activities
Japan	None	
Republic of Korea	None	
Spain	None	
Sweden	Swedish National Council for Nuclear Waste	Advises the Ministry of the Environment
Switzerland	Swiss Federal Nuclear Safety Commission	Advises the regulator and Federal Council, Federal Department of Environment, Transport, Energy, and Communications
	Interdepartmental Working Group on Radioactive Waste Management	Prepares technical and political documents for governmental decisions on radioactive waste management
	Expert Group on Radioactive Waste Disposal	Advises the regulator on geological aspects of radioactive waste disposal
United Kingdom	Committee on Radioactive Waste Management	Advises Government and ministers of the devolved administrations of Scotland, Wales, and Northern Ireland and the implementer

Table 4

COUNTRY	WASTE FORMS AUTHORIZED FOR DISPOSAL IN A DEEP GEOLOGIC REPOSITORY	CENTRALIZED INTERIM STORAGE FACILITY ESTABLISHED
WASTE FORMS AUTHORIZED FOR DISPOSAL AND ESTABLISHMENT OF CENTRALIZED INTERIM STORAGE FACILITY		
United States	Commercial and defense high-level radioactive waste (HLW), commercial spent nuclear fuel (SNF), and U.S. Department of Energy (DOE)-managed SNF	No
Belgium	No decision has been made.	No
Canada	SNF	No
China	HLW	No
Finland	SNF	No
France	HLW and long-lived intermediate-level waste	Yes. Vitrified HLW is stored at the La Hague reprocessing facility.
Germany	HLW and SNF	Yes. At Gorleben Ahaus, Rubenow, and Jülich.
Japan	HLW and transuranic (TRU) waste	Yes; Recyclable-Fuel Storage Center at Mutsu in Aomori Prefecture for SNF
Republic of Korea	SNF and possibly pyroprocessed HLW.	No
Spain	HLW, SNF, and long-lived intermediate-level waste	No. A site for the Centralized Temporary Storage facility, Villar de Cañas, was approved in 2011, but the project was suspended by the government in July 2018.
Sweden	SNF	Yes. At Oskarshamn.
Switzerland	HLW and SNF	Yes; at Würenlingen, for both HLW and SNF
United Kingdom	HLW and possibly SNF, long-lived, intermediate-level radioactive waste, and low-level waste not suitable for near-surface disposal	Yes; at Sellafield for both HLW and SNF

Waste Forms Authorized for Disposal and Establishment of Centralized Interim Storage Facilities

Until the mid-1970s, a closed fuel cycle was envisioned in which 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. Plutonium is created in nuclear reactors when uranium-238 atoms absorb neutrons. At the reprocessing plants, the plutonium and any remaining uranium would be separated from fission products, other minor actinides, and other isotopes produced via neutron capture, and recycled into fuel forms for either light-water or fast reactors. The HLW resulting from reprocessing plants would be vitrified and ultimately disposed of in a DGR. Adopting this approach meant that the nuclear fuel cycle was "closed."

In part due to concerns about nuclear-weapon materials proliferation, some nations, such as Sweden and Finland, subsequently adopted a nuclear fuel cycle that was "once-through"—that is, the SNF removed from reactors would not be reprocessed and instead be cooled, stored either on-site or at an independent centralized facility, and then disposed of directly in a DGR.

Table 4 summarizes the different waste forms authorized for disposal in a DGR and establishment of a centralized interim storage facility. There is considerable variety in materials authorized for disposal in different countries. 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. In the United States, the operating DGR at WIPP is authorized to accept defense-origin transuranic waste. The authorized waste forms listed in Table 4 pertain to regulations for radioactive waste disposal listed in the Detailed Tables for United States.

Geological Investigations

In 1957, a 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.[16] Further, the report pointed to salt as an acceptable host rock because the presence of salt implied the absence of water and the plasticity of salt would seal fractures that otherwise could preferentially conduct water flow through the waste emplacement zones. 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 DGR.

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 the country. Out of that exploration eventually came the KBS-3 approach. The KBS-3 approach places SNF in corrosion-resistant copper canisters with a cast iron insert providing mechanical strength and surrounds the copper canisters with bentonite clay in deposition holes at a depth of approximately 500 meters in the granite host rock. 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.[17]

Indeed, even countries that are thinking about or actually developing a DGR in clay (another plastic geologic material with low potential for rapid water flow), and thus believe there is no need for a robust engineered barrier system, take a systems approach[18] in developing their safety cases.

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

[17] 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 *Report to the President by the Interagency Review Group on Nuclear Waste Management* (TID-29442), Washington, D.C., 1979.

[18] The systems approach refers to use of independent and often redundant barriers—both natural and engineered—in most disposal concepts for designing a DGR.

Table 5

GEOLOGICAL INVESTIGATIONS		
COUNTRY	**GEOLOGIC ENVIRONMENTS CONSIDERED OR INVESTIGATED**	**UNDERGROUND RESEARCH LABORATORY ESTABLISHED**
United States	Salt, basalt, granite, tuff, clay, and shale	Several established but no longer operating (tuff, granite, and salt)
Belgium	Clay and shale; the current policy proposal does not specify the type of host rock.	HADES at Mol (clay)
Canada	Crystalline and sedimentary rock	Whiteshell Laboratories in Pinawa, Manitoba, was decommissioned (crystalline [granite]).
China	Primarily granite	Beishan facility under construction (granite)
Finland	Crystalline (granite, gneiss, granodiorite, and migmatite)	ONKALO in Eurajoki (crystalline)
France	Argillite, salt, and granite	Meuse/Haute Marne (argillite) Tournemire Research Tunnel (argillite) Others established but no longer operating (salt)
Germany	Salt, claystone, and crystalline host rocks	Morsleben (salt) Gorleben Dome and Asse Mine are no longer operating (salt).
Japan	Crystalline and sedimentary rocks	Tono mine (sedimentary) Mizunami (crystalline [granite]) Horonobe (sedimentary rock)
Republic of Korea	Granite	KAERI Underground Research Tunnel at Daejeon (granite) (at shallow depth only)
Spain	Granite, clay and salt	None
Sweden	Granite	Äspö in Oskarshamn (granite) Stripa Mine is no longer operating (granite)
Switzerland	Clay and granite	Mont Terri rock laboratory in Jura Canton (clay) and Grimsel Test Site in Berne Canton (granite)
United Kingdom	Higher strength rock (e.g., granite), lower strength rock (e.g., clay) and evaporite rock (e.g., salt)	None

Health and Safety Requirements for Disposal

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

Three aspects of the regulations—dose constraint, risk limit, and compliance period—seem to be of particular importance. Table 6 summarizes these three regulatory aspects for the countries considered in this report. 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.[19] There is no consensus 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.[20] The risk limit for a given consequence (e.g., dose constraint) is 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 specified by a compliance period. These regulatory choices represent social judgments informed by technical analyses.[21]

[19] One mSv equals 100 millirems.

[20] This definition is consistent with how the term is used by the International Commission on Radiological Protection.

[21] 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.

Table 6

HEALTH AND SAFETY REQUIREMENTS FOR DISPOSAL			
COUNTRY	**DOSE CONSTRAINT**	**RISK LIMIT**	**COMPLIANCE PERIOD**
United States	Yucca Mountain: 0.15 millisievert (mSv)/year 1.0 mSv/year	 Not specified Not specified	 Less than 10,000 years Greater than 10,000 years but less than 1,000,000 years
Belgium	No decision has been made.	No decision has been made.	No decision has been made.
Canada	An upper dose limit of 1.0 mSv/year established; implementer is required to provide a rationale for the dose constraint, which is a fraction of the dose limit.	Not specified	Not specified
China	No decision has been made.	No decision has been made.	At least 10,000 years
Finland	Less than 0.1 mSv/year, for normal events Release limits for various radionuclides established Impacts should be comparable to those arising from natural radioactive materials but should remain insignificantly low.	Not specified Not specified	First several thousand years Beyond first several thousand years
France	0.25 mSv/year for normal scenarios	Not specified	10,000 years
Germany	0.01 mSv/year for probable developments; 0.1 mSv/year for less probable developments	Not specified	1,000,000 years
Japan	No decision has been made.	No decision has been made.	No decision has been made.
Republic of Korea	10 mSv/year for a single scenario, including a low probability natural phenomenon and human intrusion	10^{-6}/year for a scenario, which includes natural phenomena and human intrusion	At least 10,000 years
Spain	No decision has been made.	No decision has been made.	No decision has been made.
Sweden	Not specified	Less than 10^{-6}/year for a representative individual in the group exposed to the greatest risk	Minimum of 100,000 years and can extend up to 1 million years.
Switzerland	0.1 mSv/year for expected scenarios	10^{-5}/year for expected scenarios	1 million years
United Kingdom	0.5 mSv/year for the operational period.	Guidance calls for less than 10^{-6}/year for those at greatest risk.	Not specified

Table 7

STATUS OF SITE SELECTION	
COUNTRY	**STATUS**
United States	A site at Yucca Mountain, in southern Nevada, was selected by Congress in 2002.*
Belgium	No formal siting process has been initiated.
Canada	New site-selection process was initiated in 2010, and a site selection is anticipated in 2023.
China	The Beishan site (granite) in Gansu Province in northwestern China was identified as the "candidate site" for a deep geologic repository in 2020.
Finland	Site at Olkiluoto near the municipality of Eurajoki was selected in 1999.
France	Site along the border of the Meuse and Haute-Marne departments in eastern France, near the village of Bure, was selected in 2006.
Germany	Siting process was initiated in September 2017 and is planned to be completed by 2031.
Japan	Siting process was initiated in 2002 and is planned to be completed before 2030.
Republic of Korea	Preliminary site-selection activities have been in progress since 2016. The site-selection is planned to be completed in 2028.
Spain	Formal siting process has not been initiated.
Sweden	A site at Forsmark was selected in 2009, and the Government announced its final approval in January 2022.
Switzerland	The siting process was initiated in 2008, and the implementer plans to announce the location of the repository in 2022.
United Kingdom	The siting process was initiated 2020. The implementer expects that it will take 15–20 years to complete the site-selection process.

* In 2010, the Administration determined that the proposed repository was "unworkable." Since then, Congress has not funded the Yucca Mountain Project or amended the Nuclear Waste Policy Act to change the site selection.

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 6). If one looks only at the first 10,000 years after repository closure, all the countries regard as acceptable a dose constraint that falls within a range of 0.1–0.3 millisievert (mSv)/year. However, some of those countries require that the dose constraint also be satisfied for compliance periods that extend to 1,000,000 years. Risk limits range from 10^{-5} to 10^{-6}/year (i.e., a probability of 1 in 10,000 to 1 in a million) depending on the compliance period and the likelihood that a particular scenario evolves.

Status of the Site-Selection Process

Experience shows potential DGR sites have to pass through both technical and social filters.[22] Some countries, like Germany, plan to identify potential sites based first on technical considerations and then determine whether social and political realities will permit the site's development as a repository. Other countries, like Japan and the United Kingdom, reverse the order, looking first for volunteer communities and then evaluating a site's technical merits. Still other countries have concluded that moving forward with developing a DGR at this time is simply premature.

Experience also shows that a siting process can get bogged down because of failure of particular sites to pass through either technical or social filters (or both). In some countries, programs have had to be altered to address the technical and social concerns that arose.[23] These reorganizations have at the very least, resulted in significant programmatic delays. In other countries, technical or social controversies, or the prospect of them, have led policy makers to defer for many decades the development of a DGR. Table 7 provides information on the status of the site-selection process in the 13 nations considered here. Finland, France, and Sweden have completed their site-selection process. Switzerland and Canada are in the process of finalizing their sites in 2022 and 2023, respectively.

[22] NWTRB. 2015. *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis.* Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/siting_report_analysis.pdf?sfvrsn=9. (Accessed January 20, 2022.)

[23] Ibid.

Anticipated Start of Repository Operations

Determining when a repository will begin operations depends on many factors. Typically, the anticipated start of repository operations can be reasonably projected if there is a formal siting process and a site has been selected or if the site-selection process is well advanced. After site selection, repositories can begin operations only after regulatory approvals for construction are obtained (around 5 years), the repository is constructed (5–10 years or more), and regulatory approvals for operation are obtained (several years). Certainty of anticipated start of repository operations increases as a country passes through the site-selection process and into the subsequent phases. Table 8 summarizes the anticipated start of repository operations. Two of the four countries that have selected a site for a DGR—Finland and France—have announced that they anticipate the start of operations in this decade. Finland submitted its operating license application in December 2021 and plans to begin repository operations in 2025. Pending regulatory approvals, repository operations in Sweden are expected to start in mid-2030s. Canada and Japan plan to begin their repository operations in 2040. Repository operations in Switzerland and China are planned to start in 30–40 years. The remaining 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.

Table 8

ANTICIPATED START OF REPOSITORY OPERATION

COUNTRY	DATE
United States	No decision has been made.
Belgium	No decision has been made.
Canada	In 2040
China	In roughly the 2050 time frame
Finland	In 2025
France	In 2025-2027 (Pilot industrial phase)
Germany	No decision has been made.
Japan	Sometime before 2040
Republic of Korea	By 2053
Spain	In 2063
Sweden	Sometime in 2030s
Switzerland	No sooner than 2060
United Kingdom	No decision has been made.

A Concluding Comment

When the radioactive waste management community in the United States and abroad began work related to developing a DGR in their respective nations, the task was perceived by some 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 that includes establishing 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 (Finland, Sweden, and France) of the 13 countries identified above close to implementing a technically and politically accepted effort to develop a DGR, it is difficult to infer what, if anything, is a "magical recipe" for success. This question, however, is explored in greater depth in a Board report.[24] 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 DGR.

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[24] NWTRB. 2015. *Designing a Process for Selecting a Site for a Deep-Mined, Geologic Repository for High-Level Radioactive Waste and Spent Nuclear Fuel: Detailed Analysis.* Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/siting_report_analysis.pdf?sfvrsn=9. (Accessed January 20, 2022.)

Detailed Tables

The Board identified 30 key attributes associated with national radioactive waste management programs. Half of these attributes relate to the institutional arrangements established in each country. The remaining attributes relate to the technical aspects. 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 (IAEA) as part of the periodic meetings under the provisions of the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.*[25]

In 2009, drafts of the detailed tables were sent out to in-country experts for peer review.[26] At least one expert from each country, and as many as three, reviewed the tables and provided comments. 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.[27] Subsequent updates in 2016)[28] and in this report were based mainly on information available in published and online sources. For this update, the Board wishes to express its appreciation to Dr. Maarten Van Geet and Dr. Peter De Preter from Organisme national des déchets radioactifs et des matières fissiles/Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen (ONDRAF/NIRAS), Dr. Thilo von Berlepsch from Bundesgesellschaft für Endlagerung mbH (BGE), and Dr. Sarah Vines and Dr. Kurt Smith from Nuclear Waste Services for the help and advice they provided in updating information related to Belgium, Germany, and the United Kingdom, respectively.

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[25] IAEA. 2021. "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management Documents." Accessed January 19, 2022. https://www.iaea.org/topics/nuclear-safety-conventions/joint-convention-safety-spent-fuel-management-and-safety-radioactive-waste/documents.

[26] U.S. Nuclear Waste Technical Review Board (NWTRB). 2009. Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/nwtrb-sept-09.pdf?sfvrsn=7.

[27] In the Detailed Tables, the reader will find two entries that appear similar on their face: "no decision has been 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.

[28] NWTRB. 2016. Survey of National Programs for Managing High-Level Radioactive Waste and Spent Nuclear Fuel: Update. Arlington, Virginia: U.S. Nuclear Waste Technical Review Board. https://www.nwtrb.gov/docs/default-source/reports/survey_report_2016.pdf?sfvrsn=6. (Accessed January 20, 2022.)

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

KEY ATTRIBUTES—INSTITUTIONAL ARRANGEMENTS

1. *Legislation specific to radioactive waste management:* Laws (as amended) 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, and 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 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 (DGR) 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 DGR—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 DGR.

7. *Regulations and decrees applicable to licensing a DGR—environmental impact assessment:* Rules and standards created by government agencies and ministries that structure the processes and the required analyses for evaluating the environmental effects of developing a DGR.

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

9. *Formal legislative/executive approvals required for developing a DGR—selection of a waste management option:* Decisions about whether to develop a DGR or to adopt some other option, such as indefinite storage or separation and transmutation, 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 DGR—site selection:* The decision to choose a candidate or final location for a DGR. 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 DGR—facility construction and operation:* The decision to permit the construction and operation of a DGR. 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 DGR) 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 DGR 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 ASPECTS

1. *Operating nuclear reactors/generating capacity:* The number and gross generating capacity (in gigawatts electric) of reactors operating as of February 4, 2022.[29] The generating capacity of those reactors is the nominal capacity reported to authorities.
2. *Reprocessing included in fuel cycle:* Whether spent nuclear fuel (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/high-level radioactive waste (HLW) to a DGR:* Transportation options available for those countries where a site has been selected or where particular sites are being actively considered.
4. *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 DGR:* Host rocks that appear to be potentially suitable for a DGR. The host rocks may have been considered or investigated in bench or desk studies, by surface investigation, or by at-depth exploration.
6. *Engineered barrier system—design:* How the engineered part of the DGR is to be constructed.
7. *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.
8. *Waste forms authorized to be disposed of in a DGR:* The type of material that would be disposed of in a DGR.

[29] IAEA. 2022. "Power Reactor Information System." Accessed February 4, 2022. https://pris.iaea.org/pris/.

9. *Underground research laboratories:* Laboratories that have been developed (either operational or under construction or decommissioned) where experiments were (or planned to 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.
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. *Long-term health and safety requirements:* Specific regulations and standards establishing dose constraints, risk limits, and compliance periods that must be satisfied before a DGR can be licensed.
12. *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 DGR.
13. *Requirements for retrievability:* Specific laws or regulations establishing the duration within which waste must be able to be retrieved from a DGR. Also, specific laws and regulations establishing how the entire disposal process can be reversed.
14. *Status of repository site-selection process:* The stage of the national decision for selecting a site for a DGR.
15. *Anticipated start of repository operations:* Year in which either the implementer or an appropriate governmental authority has stated publicly that a DGR will be available to begin accepting waste for disposal.

United States, Belgium, Canada

Institutional Arrangements

Country	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)	U.S. Department of Energy (DOE) (government agency)	U.S. Environmental Protection Agency (EPA) (sets environmental standards) U.S. Nuclear Regulatory Commission (NRC) (implements standards and licenses facilities)	U.S. Nuclear Waste Technical Review Board (NWTRB) (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. The fee has not been collected since May 2014.
Belgium	Law of 8 August 1980, as amended Law of 3 June 2014 transposing European Directive 2011/70 (implementation) Law of 29 March 1958, modified by Law of 15 April 1994 (regulation)	National Agency for Radioactive Waste and Enriched Fissile Materials (Organisme national des déchets radioactifs et des matières fissiles/ Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen [ONDRAF/NIRAS]) (government agency)	Federal Agency for Nuclear Control (Federaal Agentschap voor Nucleaire Controle [FANC])	None	Long-Term Fund Costs of developing a repository will be fully paid by waste producers. Payments determined by Royal Decree 25 April 2014 Pre-license expenditures (e.g., research and development [R&D]) are paid by the waste producers.
Canada	Nuclear Fuel Waste Act (2002) Nuclear Safety and Control Act (2000)	Nuclear Waste Management Organization (NWMO), subject to Government approval of key policies and decisions (private, not-for-profit organization formed by the nuclear electricity producers)	Canadian Nuclear Safety Commission (CNSC)	Advisory Council; Adaptive Phased Management Geoscientific Review Group; Council of Elders and Youth (advises the implementer) Independent Advisory Group (advises the regulator)	Nuclear Fuel Waste Act Trust Fund: Owners pay into the fund, subject to the formula approved by Government. Pre-license expenditures are paid contemporaneously by owners.

*Appropriations from the Nuclear Waste Fund are controlled by the U.S. Congress and are subject to annual apportionment.

Institutional Arrangements

Country	Regulations and Decrees Applicable to Licensing a DGR			Formal Legislative/Executive Approvals Required for Developing a DGR		
	Site Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site Selection	Facility Constructions and Operations
United States*	U.S. Nuclear Regulatory Commission 10 CFR† 60 U.S. Department of Energy 10 CFR 960 (generic site) and 10 CFR 963 (Yucca Mountain specific) (radioactive waste specific)	National Environmental Policy Act Council of Environmental Quality 40 CFR 1500 (generic) Nuclear Waste Policy Act (1982) (radioactive waste specific)	U.S. Nuclear Regulatory Commission 10 CFR 60 and 10 CFR 63 U.S. Environmental Protection Agency 40 CFR 191 (generic) and 40 CFR 197 (Yucca Mountain specific) (radioactive waste specific)	U.S. 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	No specific regulations for siting a DGR	Strategic Environmental Assessment (Law 13 of February 2006) (radioactive waste specific) Environmental Impact Statement as part of general licensing procedure (Royal Decree of 20 July 2001)	General licensing procedure (nuclear facilities) in Royal Decree of 20 July 2001 GRR-2001 Federal Agency for Nuclear Control (radioactive waste specific)	No formal policy decision has been made, as required by the EU Directive 2011/70. In 2020, a policy proposal for geological disposal was submitted by the implementer to the Federal Government for approval.	No decision has been made.	Construction and operating licenses are granted by Government through a royal decree on the advice of the regulator.
Canada	Canadian Nuclear Safety Commission Regulations under the Nuclear Safety and Control Act Clauses 3 and 4 (nuclear facility specific) Guidance on Deep Geological Repository Site Characterization Regulatory Document-1.2.1 (2021) (radioactive waste specific)	Environmental Protection Act Environmental Assessment Act (2012) Regulations under the Canadian Environmental Assessment Act (generic)	Canadian Nuclear Safety Commission Safety Case for the Disposal of Radioactive Waste Regulatory Document – 2.11.1, Volume III, Version 2 (2021) [1] (radioactive waste specific)	Government approved a recommendation by the implementer to implement a geologic disposal strategy of Adaptive Phased Management. An optional strategy of shallow underground storage also was adopted (2007).	The CNSC has the full authority to decide on the Site Preparation License.	After the approval by the CNSC of licenses to construct and possess/receive waste, no further action is required.

*Does not include institutional arrangements for the Waste Isolation Pilot Plant.
† CFR - Code of Federal Regulations.

Institutional Arrangements

Country	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' 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 or received benefits under those provisions.	No
Belgium	No decision has been made regarding the decision-making process for a DGR. This process will be established by Royal Decree as part of National Policy once policy decision on the long-term management option has been taken.	No decision has been made regarding the decision-making process for a DGR.	No decision has been made regarding the decision-making process for a DGR. The law of 8 August 1980 envisions creation of a specific fund that will finance the integration of a disposal facility in a local community.	No decision has been made. The National Policy will be established in a stepwise manner, according to the law of June 3, 2014, transposing Directive 2011/70/Euratom.
Canada	Under the Adaptive Phased Management strategy, only communities willing to host a DGR will be considered.	No decision has been made.	No decision has been made.	Yes

Technical Attributes

Country	Operating Nuclear Reactors/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a DGR	Centralized Interim Storage Facility Established
United States	93 nuclear reactors (95.5 gigawatts of electric power [GWe]) 2 nuclear reactors are under construction (2.2 GWe)	The U.S. reprocessed defense-related SNF as part of its weapons plutonium production program. Small amounts of commercial SNF were reprocessed at West Valley, New York. 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
Belgium	7 nuclear reactors (5.9 GWe) The nuclear phase-out law of 2003 limits the operational lifetimes of the nuclear reactors to 40 (4 reactors) and 50 (3 reactors) years. The current fleet of reactors is expected to be retired by 2025 per this law.	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 (1966–1974).	No decision has been made.	Yes. HLW is stored at the Belgoprocess site in Dessel.
Canada	19 nuclear reactors (13.6 GWe)	No	No decision has been made.	No

Technical Attributes

Country	Geologic Environments Considered or Investigated for a DGR	Engineered Barrier System: Design	Engineered Barrier System: Importance to Safety Case	Waste Forms Authorized to Be Disposed of in a DGR	Underground Research Laboratories
United States	Salt, basalt, tuff, granite, clay, and shale	For Yucca Mountain: Double-shelled waste package composed of Alloy 22 (outer) and carbon steel (inner); titanium drip shield	For Yucca Mountain: Very important	Commercial and defense HLW, commercial SNF, and DOE-managed SNF	Several established but no longer operating (tuff, granite, and salt) Waste Isolation Pilot Plant (salt) has been an operating transuranic waste repository since 1999 and DOE R&D activities resumed in 2017.
Belgium	The current policy proposal for disposal does not specify the type of host rock [2]. Research has focused mostly on poorly indurated clays like Boom clay and Ypresian clay, although shales are also abundant in Belgium.	Current reference design, for research and planning purposes, 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.	Though the host rock is the primary barrier, different safety functions are assigned to the engineered barriers [3].	No decision has been made. The current plans by the waste producers consider disposal of both HLW and SNF. (There is no final decision regarding restarting reprocessing.)	HADES Project was initiated in 1974 in Mol. (Boom clay)
Canada	Granite or sedimentary rock	The current reference design consists of a copper-coated steel canister surrounded by a bentonite buffer [4].	No decision has been made.	SNF	Whiteshell Laboratories in Pinawa, Manitoba (granite) (decommissioned in 2010)

Technical Attributes

Country	Requirements for Defense in Depth	Long-Term Health and Safety Requirements	Methodology for Demonstrating Compliance with Postclosure Standards	Requirements for Retrievability
United States	Multiple barriers (both natural and engineered) are required. No requirement for barrier redundancy or barrier-specific requirements	For Yucca Mountain: 0.15 millisievert (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	For Yucca Mountain, probabilistic analysis was used. The performance assessment is an analysis that: (1) identifies the features, events, processes (except human intrusion), and sequences of events and processes (except human intrusion) that might affect the Yucca Mountain disposal system and their probabilities of occurring. (2) examines the effects of those features, events, processes, and sequences of events and processes upon the performance of the Yucca Mountain disposal system. (3) estimates the dose incurred by the reasonably maximally exposed individual, including the associated uncertainties, as a result of releases caused by all significant features, events, processes, and sequences of events and processes, weighted by their probability of occurrence.	Repository must be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated.
Belgium	General defense-in-depth requirement based on "Safety requirements for nuclear facilities" regulation (Royal Decree of 30 November 2011)	While a general dose limit for nuclear facilities is applicable, no decision has been made regarding the dose constraint for a DGR.	Technical guidance will be issued by the regulators on compliance with operational and long-term protection criteria.	No decision has been made. Law of 3 June 2014 requires that retrievability requirements need to be defined in the National Policy.
Canada	No requirement for barrier redundancy or barrier-specific requirements	CNSC specified a public dose limit of 1 mSv/year [1]. Implementer is required to provide rationale for dose constraint, which is a fraction of the dose limit and is used as a design tool. The implementer will establish a compliance period considering several factors (e.g., predicted time of peak radiological impact, type and severity of events).	The postclosure safety assessment includes analysis of a nominal scenario, possible disruptive events, and the potential radiological and non-radiological impacts on people and the environment. The impacts are determined quantitatively using mathematical models [1].	In the Adaptive Phased Management plan, retrievability of the canisters is not planned after their emplacement in the repository. However, retrieval of the canisters is allowed if needed for safety or other reasons [5]. This requirement has not yet been incorporated into regulations.

Technical Attributes

Country	Status of Repository Site-Selection Process	Anticipated Start of Repository Operations
United States	The Yucca Mountain site has been characterized and was approved for development of a repository by Congress in 2002. In 2010, the Administration maintained that the Yucca Mountain Project is "unworkable." Since then, Congress has not funded the Project or amended the Nuclear Waste Policy Act to change the site selection.	No decision has been made.
Belgium	No active siting process for an HLW/SNF repository is being carried out because a policy decision on the long-term management option is awaited.	No decision has been made.
Canada	A process for selecting a site was initiated in 2010. Twenty-three communities initially expressed interest. Based on its evaluations of site-suitability criteria, the implementer has narrowed its consideration to two communities—Ignace and South Bruce. The site-selection process is expected to be completed by 2023 [6].	The implementer plans to initiate the design and construction of the repository in 2033 and to begin operations in 2040 [6].

References for United States, Belgium, and Canada:

1. Canadian Nuclear Safety Commission (CNSC). 2020. REGDOC-2.11.1, *Waste Management, Volume III: Safety Case for the Disposal of Radioactive Waste, Version 2*. Ottawa, Canada: Canadian Nuclear Safety Commission. https://nuclearsafety.gc.ca/eng/acts-and-regulations/regulatory-documents/published/html/regdoc2-11-1-vol3-ver2/index.cfm. (Accessed January 20, 2022.)

2. Federal Agency for Nuclear Control (FANC). 2020. *Kingdom of Belgium – Seventh Meeting of the Contracting Parties to the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.* Ivry-sur-Seine, France: Federal Agency for Nuclear Control. https://afcn.fgov.be/fr/system/files/2020-11-10-jc-rapport-be-2020.pdf. (Accessed on January 20, 2022.)

3. Organisme national des déchets radioactifs et des matières fissiles/ Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen (ONDRAF/NIRAS). 2013. *ONDRAF/NIRAS Research, Development and Demonstration (RD&D) Plan for the geological disposal of high-level and/or long-lived radioactive waste including irradiated fuel if considered as waste.* NIROND-TR 2013-12 E. Brussels, Belgium: ONDRAF/NIRAS. https://www.ondraf.be/sites/default/files/2020-05/ONDRAFNIRAS%20Research%2C%20Development%20and%20Demonstration%20%28RD%26D%29%20Plan.pdf. (Accessed February 16, 2022.)

4. Nuclear Waste Management Organization (NWMO). "Multiple Barrier System." Accessed February 22, 2022. https://www.nwmo.ca/en/A-Safe-Approach/Facilities/Deep-Geological-Repository/Multiple-Barrier-System.

5. NWMO. 2008. "Monitoring and Retrievability." Accessed January 20, 2022. https://www.nwmo.ca/en/~/media/Site/Files/PDFs/2015/11/18/10/21/NWMO-Information-Sheet--Monitoring-and-Retrievability.ashx.

6. NWMO. 2021. Annual Report 2020. Ottawa, Canada: NWMO. https://www.nwmo.ca/~/media/Site/Reports/2021/03/15/20/13/2020-NWMO-Annual-Report.ashx?la=en. (Accessed January 20, 2022.)

China, Finland, France

Institutional Arrangements

Country	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)	The China Atomic Energy Authority (CAEA) is responsible for developing plans and projects. China National Nuclear Corporation (CNNC) manages implementation activities [1]. (Government-owned corporation)	National Nuclear Safety Administration (NNSA) within the Ministry of Ecology and Environment	No decision has been made.	Interim Procedures on Collection, Utilization and Management of the Funds for Treatment and Disposal of Spent Fuel at Nuclear Power Plants. Currently $0.004/kWh
Finland	Nuclear Energy Act (1987) Nuclear Energy Decree (1988)	Posiva Oy (joint waste management company created by two utilities, Teollisuuden Voima Oyj and Fortum Power and Heat Oy)	Radiation and Nuclear Safety Authority (Säteilyturvakeskus [STUK]) (advises Government on the safety of proposed facilities)	None	National Nuclear Waste Management Fund Generators estimate cost of radioactive waste disposal. They pay annually the difference between fund target and amount existing in the fund.
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) Act No. 2016-1015 (2016) (specifies conditions for reversibility)	National Agency for Radioactive Waste Management (Agence nationale pour la gestion des déchets radioactifs [Andra]) It is supervised by the Ministries for Energy, Research and the Environment. (Government-funded industrial and commercial institution)	Nuclear Safety Authority (Autorité de sûreté nucléaire [ASN])	National Review Board (Commission nationale d'évaluation 2 [CNE2]) (advises implementer, Government, and Parliament)	The waste generators must contribute to a fund, which is supervised by an independent commission established under the 2006 Planning Act.

Institutional Arrangements

Country	Regulations and Decrees Applicable to Licensing a DGR			Formal Legislative/Executive Approvals Required for Developing a DGR		
	Site Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site Selection	Facility Constructions and Operations
China	National Nuclear Safety Administration Guidelines on Siting of a Radioactive Waste Geological Repository HAD-406/06-2013 (radioactive waste specific)	Law of the People's Republic of China on Environmental Protection (1989) Law of the People's Republic of China on Environmental Impact Assessment (2003) (generic)	State Council Regulations on the Safety of Radioactive Waste Management (2011) National Nuclear Safety Administration Regulations on the Safety Control for Civilian Nuclear Installations HAF001 (1986) (radioactive waste specific)	Law of the People's Republic of China on Prevention and Control of Radioactive Pollution (2003)	Ministry of Ecology and Environment / National Nuclear Safety Administration	Ministry of Ecology and Environment/National Nuclear Safety Administration Management Measures for Licensing the Storage and Disposal of Solid Radioactive Waste (2013)
Finland	Government Decree 736-2008 on the Safety of the Disposal of Nuclear Waste Radiation and Nuclear Safety Authority Regulation on the Safety of Disposal of Nuclear Waste (STUK Y/4/2018) (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 Regulation on the Safety of Disposal of Nuclear Waste (STUK Y/4/2018) Disposal of Nuclear Waste Guide (YVL D.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)	A construction license for a DGR located in the Eurajoki Municipality was granted by the Government on the advice of Radiation and Nuclear Safety Authority in 2015. Same process of regulatory review followed by Government decision applies for approval for operations.
France	Nuclear Safety Authority Safety Guide for Final Disposal of Radioactive Waste in Deep Geologic Formations (2008) (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 (2008) (radioactive waste specific)	Research on Radioactive Waste Management Act (1991) Planning Act Concerning the Sustainable Management of Radioactive Materials and Waste (2006)	Approval of a site in the Meuse/Haute-Marne region in the Planning Act Concerning the Sustainable Management of Radio-active Materials and Waste (2006)	No decision has been made by the French Parliament. Approval will be based on the advice of the Nuclear Safety Authority and National Review Board.

Institutional Arrangements

Country	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 has been made.	No decision has been made.	No decision has been made.	No decision has been made.
Finland	Yes, by Municipal Council. The Eurajoki nuclear community approved a positive statement, thereby not vetoing siting of a an HLW/SNF repository.	A veto can be exercised before the Government makes a Decision-in-Principle on the repository. The 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 devel-opment, including a dedicated tax on Basic Nuclear Installations.	No

Technical Attributes

Country	Operating Nuclear Reactors/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a DGR	Centralized Interim Storage Facility Established
China	54 nuclear reactors (50.7 GWe) 14 nuclear reactors are under construction. (14.8 GWe)	Yes, a pilot reprocessing plant has been constructed at the Lanzhou Nuclear Fuel Complex in Gansu Province and is expected to be operational in 2025 [2].	No decision has been made.	No, although a small amount of SNF is stored at the reprocessing plant in Lanzhou.
Finland	4 nuclear reactors (2.8 GWe) 1 nuclear reactor 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
France	56 nuclear reactors (61.3 GWe) 1 nuclear reactor is under construction (1.6 GWe)	Yes	Most of the waste packages will be transported by rail to the DGR [3].	None for SNF. Vitrified HLW is stored at the La Hague reprocessing plant.

Technical Attributes

Country	Geologic Environments Considered or Investigated for a DGR	Engineered Barrier System: Design	Engineered Barrier System: Importance to Safety Case	Waste Forms Authorized to Be Disposed of in a DGR	Underground Research Laboratories
China	Primarily granite; potential host rocks also include clays and shale.	No decision has been made.	No decision has been made.	HLW	Construction of the Beishan facility started in June 2021 and is expected to be completed by 2028 [4].
Finland	Crystalline* (granite, gneiss, granodiorite, and migmatite)	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	SNF	Construction of ONKALO underground rock characterization facility at the Eurajoki site began in 2004. Experimental work is being conducted during construction of the repository. (crystalline)
France	Argillite,* salt, and granite	Vitrified waste placed within stainless steel packages	Minimal	HLW and long-lived, intermediate-level waste	Meuse/Haute-Marne facility near the village of Bure began operations in 2000 and experiments continue. (argillite)

*Host rock for the selected DGR.

Technical Attributes

Country	Requirements for Defense in Depth	Long-Term Health and Safety Requirements	Methodology for Demonstrating Compliance with Postclosure Standards	Requirements for Retrievability
China	No decision has been made.	No decision has been made about dose or risk limits. Compliance period will be at least 10,000 years.	No decision has been made.	No decision has been made.
Finland	No requirement for barrier redundancy or barrier-specific requirements; the barriers should complement each other so that a deficiency in one will not jeopardize long-term safety.	For the first several thousand years, dose limit is less than 0.1 mSv/year for normal events. Beyond the first several thousand years, impacts can be comparable to those arising from natural radio-active materials but should remain negligible.	Compliance is to be demonstrated by means of a 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. The safety case shall separately assess the uncertainties included in the data, models, and analyses and their significance.	The Government's Decision-in-Principle (2000) included a retrievability requirement that the regulator later removed. The Government reimposed this requirement as a condition of the license to construct the repository [5].
France	Required Safety Guide for Final Disposal of Radioactive Waste in Deep Geologic Formations Chapters 5.1 and 6.1	Dose limit is 0.25 mSv/year for normal scenarios. Compliance period is 10,000 years. Less demanding evidence is required for compliance greater than 10,000 years.	Compliance is shown through the deterministic analysis of several normal and altered scenarios. In addition, sensitivity calculations are used to evaluate the impact of uncertainty.	The repository must be designed so that it is "reversible" for the entire life of the repository [6]. Reversibility is a management concept that requires technical retrievability.

Technical Attributes

Country	Status of Repository Site-Selection Process	Anticipated Start of Repository Operations
China	Following an initial evaluation of several sites, the Beishan site (granite) in Gansu Province in northwestern China was identified as the candidate site for a DGR in 2020 [7, 8].	The repository construction is planned to be completed around 2041−2050 [7].
Finland	Olkiluoto, a site at Eurajoki in migmatite, was approved by the Government in 2000 and by Parliament in 2001. In 2015, the Government approved construction of the DGR in the municipality of Eurajoki.	The construction of the geological repository started in July 2021. The implementer, Posiva, applied for an operating license in December 2021 [9]. Final disposal activities are expected to begin in 2025.
France	Site along the border of the Meuse and Haute-Marne departments in eastern France, near the village of Bure, was selected in 2006. An underground zone of 30 km^2 has been identified for disposal. The selection of a specific location within that area for development of a DGR is under way.	Sometime in the 2025−2027 (Pilot industrial phase) [10].

References for China, Finland, and France:

1. Wang, Ju, Rui Su, Liang Chen, Xingguang Zhao, Yuemiao Liu, and Zihua Zong. 2017. "Geological Disposal Program for High Level Radioactive Waste and the Plan for the Underground Research Laboratory in China." In *International Approaches for Nuclear Waste Disposal in Geological Formations: Geological Challenges in Radioactive Waste Isolation—Fifth Worldwide Review,* edited by Boris Faybishenko, Jens Birkholzer, Peter Persoff, David Sassani, and Peter Swift, 5-1 to 5-27. Washington, DC: U.S. Department of Energy, Office of Scientific and Technical Information. https://doi.org/10.2172/1353043. (Accessed January 20, 2022.)
2. Zhang, Hui. 2021. "China starts construction of a second 200 MT/year reprocessing plant." International Panel on Fissile Materials, March 21, 2021. https://www.belfercenter.org/publication/china-starts-construction-second-200-mtyear-reprocessing-plant. (Accessed January 20, 2022.)
3. Andra [Agence nationale pour la gestion des déchets radioactifs]. 2022. "From preparation of waste packages to disposal." Accessed January 20, 2022. https://international.andra.fr/projects/cigeo/cigeos-facilities-and-operation/preparation-waste-packages-disposal.
4. World Nuclear News. 2021. "China starts building underground lab." World Nuclear News, June 21, 2021. https://world-nuclear-news.org/Articles/China-starts-building-underground-lab#:~:text=Construction%20of%20the%20Beishan%20Underground,Authority%20(CAEA)%20has%20announced.&text=In%202019%2C%20the%20project%20was,the%20leader%20of%20the%20project. (Accessed February 23, 2022.)
5. Vira, Juhani. 2017. "Geological repository for high-level nuclear waste becoming reality in Finland." In Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste (Second Edition), edited by Michael J. Apted, Joonhong Ahn, 645-666. https://www.sciencedirect.com/science/article/pii/B9780081006429000232. (Accessed February 23, 2022.)
6. Andra. 2022. "Retrievability of the waste package disposed of in Cigéo." Accessed January 20, 2022. https://international.andra.fr/retrievability-waste-package-disposed-cigeo.
7. International Atomic Energy Agency (IAEA). 2017. The People's Republic of China Fourth National Report for the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. Beijing, (China: IAEA. https://www.iaea.org/sites/default/files/national_report_of_china_for_the_6th_review_meeting_-_english.pdf. Accessed February 23, 2022.)
8. Carter, Bridget and Gerald Nieder-Westermann. 2021. "China Begins Construction of its First Underground Research Laboratory for High Level Waste Disposal." IAEA News, July 23, 2021. https://www.iaea.org/newscenter/news/china-begins-construction-of-its-first-underground-research-laboratory-for-high-level-waste-disposal. (Accessed April 1, 2022.)
9. Posiva Solutions. 2022. "Posiva's operating licence application." Posiva News, December 15, 2021. https://www.posivasolutions.com/news/pressreleasesstockexchangereleases/2021/posiva8217soperatinglicenceapplication.html. (Accessed January 20, 2022.)
10. Leverd, P.C. 2022. "The Industrial Pilot Phase of the French Deep Geological Repository Project." Phoenix, Arizona: Waste Management Symposium.

Germany, Japan, Republic of Korea

Institutional Arrangements

Country	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, as amended) Nuclear Licensing Procedure Ordinance (1977) Federal Mining Act (1980) Waste Disposal Advance Payments Ordinance (1982) Radiation Protection Ordinance (2001) Site Selection Act (2013, as amended) Act on the Establishment of a Federal Office for the Safety of Nuclear Waste Management (2014) Act on the Reorganisation of the Organisational Structure in the Field of Disposal (2016) Act on the Reorganisation of Responsibility in Nuclear Waste Management (2017) Radiation Protection Act (2018)	Federal Company for Radioactive Waste Disposal (BGE) (Government-owned corporation)	Federal Office for the Safety of Nuclear Waste Management (Bundesamt für die Sicherheit der nuklearen Entsorgung [BASE]), located within the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection	Nuclear Waste Management Commission (Entsorgungskommission [ESK]) (advises Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection) National Citizens' Oversight Committee (supports site selection activities) [1]	Fund for financing of nuclear waste management The nuclear power plant operators provided the basic amount for this fund. The Federal Government is responsible for financing the storage and disposal activities.
Japan	Designated Radioactive Waste Final Disposal Act (2000, as amended) Act on the Regulation of Nuclear Source Material, Nuclear Fuel Material, and Reactors (1957, as amended) Radiation Hazards Prevention Act (2017) Basic Policy on Final Disposal of Designated Radioactive Wastes (2015)	Nuclear Waste Management Organization of Japan (NUMO) (private. non-profit organization established by the owners of nuclear power plants) (supervised by Ministry of Economy, Trade and Industry)	Nuclear Regulation Authority (NRA) located within the Ministry of Environment	None	High-Level Waste Fund and Transuranic Waste Fund The Ministry of Economy, Trade, and Industry notifies owners of nuclear power plants (for HLW) and reprocessing and mixed oxide fuel fabrication plants (for transuranic waste) of the amount that needs to be deposited annually.
Republic of Korea	Atomic Energy Promotion Act (1988) Nuclear Safety Act (1988) Radioactive Waste Management Law (2008)	Korea Radioactive Waste Agency (KORAD) (government agency that reports to the Ministry of Trade, Industry and Energy [MOTIE])	Nuclear Safety and Security Commission (NSSC) (reports to the Prime Minister)	None	"Polluter pays" principle adopted in Atomic Energy Act Radioactive Waste Management Fund; no decision has been made on implementation except that the generator pays only after waste is accepted for centralized storage or disposal.

Institutional Arrangements

Country	Regulations and Decrees Applicable to Licensing a DGR			Formal Legislative/Executive Approvals Required for Developing a DGR		
	Site Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site Selection	Facility Constructions and Operations
Germany	Repository Site Selection Act (2013) [2] Geological Data Act (2020)	Environmental Impact Assessment Act (2010) (generic)	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste (2010) (radioactive waste specific)	Atomic Energy Act (1959, 2011)	BASE and final approval by Government	BASE, located within the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection
Japan	None; the implementer must follow the three-step procedure established by the Ministry of Economy, Trade, and Industry and obtain approval after each step.	No decision has been made.	Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety Rules for Category 1 Waste Disposal for Nuclear Fuel Material (radioactive waste specific)	Designated Radioactive Waste Final Disposal Act (2000, 2007)	With the consent of the Cabinet, the Minister of Economy, Trade, and Industry must give approval.	With the consent of the Cabinet, the Minister of Economy, Trade, and Industry must give approval.
Republic of Korea	No decision has been made for HLW/SNF repository.	No decision has been made for HLW/SNF repository.	Nuclear Safety and Security Commission Standards for Radiation Protection (2013) (radioactive waste specific)	Atomic Energy Act (1988)	No decision has been made.	No decision has been made.

Institutional Arrangements

Country	Interactions with Local Jurisdictions: Local Veto	Interactions with Local Jurisdictions: Limitations on Local Veto	Interactions with Local Jurisdictions: Benefits to Be Provided to Local Community for Accepting a Facility	Explicit Adoption of a Staged Decision-Making Process
Germany	No local veto is foreseen. Decision shall be based on safety.	Not applicable	Currently there are no benefits planned for local communities. A fund (similar to funds for the Asse and Konrad repositories) may be set up in the future.	"Stepwise optimization" is mandated under the Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste (2010).
Japan	The mayor of host community and the Prefectural Governor must agree to participate in the siting process.	None	Under a plan issued in 2002 by NUMO, if a local community agrees to be included in a literature survey of potential sites, that community and its neighboring communities will receive up to \$18 million. If the community subsequently allows surface-based site investigations, that community and its neighboring communities will receive up to \$65 million.	Yes
Republic of Korea	No decision has been made.	No decision has been made.	No decision has been made.	No decision has been made for HLW/SNF disposal.

Technical Attributes

Country	Operating Nuclear Reactors/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a DGR	Centralized Interim Storage Facility Established
Germany	3 nuclear reactors (4.1 GWe) The utilization of nuclear fission for the commercial generation of electricity will be terminated by 2022 at the latest.	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. Reprocessing of most of German commercial SNF was done in France, although smaller amounts were reprocessed in the United Kingdom, Belgium, and Germany.	No decision has been made.	Facilities at Gorleben, Ahaus, Rubenow, and Jülich store commercial SNF. HLW is stored at Gorleben. Under the amendments to the Atomic Energy Act in 2002, commercial SNF subsequently produced has to be stored at nuclear power plants. HLW repatriated after December 31, 2013, from France and the United Kingdom must be stored at the reactor's site.
Japan	33 nuclear reactors (31.7 GWe) 2 nuclear reactors are under construction. (2.6 GWe)	Commercial SNF from Japan was reprocessed in France and the United Kingdom. In addition, reprocessing takes place at the Tokai Reprocessing Plant. The construction of the Rokkasho Reprocessing Plant is expected to be completed in 2022–2023 [3].	No decision has been made.	Yes, at the Recyclable-Fuel Storage Center at Mutsu in Aomori Prefecture for SNF
Republic of Korea	24 nuclear reactors (23.1 GWe) 4 nuclear reactors are under construction. (5.4 GWe)	All SNF that was used in commercial power reactors (both pressurized-water reactor [PWR] and Canada deuterium uranium [CANDU]) is of U.S. origin. The U.S. has refused to permit reprocessing that fuel.	No decision has been made.	Construction recommended by the Public Engagement Commission on Spent Nuclear Fuel Management, but no schedule for beginning to site a facility has been established.

Technical Attributes

Country	Geologic Environments Considered or Investigated for a DGR	Engineered Barrier System		Waste Forms Authorized to Be Disposed of in a DGR	Underground Research Laboratories
		Design	Importance to Safety Case		
Germany	Salt, claystone, and crystalline host rocks [4]	No decision has been made.	No decision has been made. The engineered barrier system will be important if the crystalline host rock is chosen.	HLW and SNF	The Morsleben repository is being used to test new techniques for final disposal. Underground exploration at the Gorleben site was launched in 1986 but was suspended in 2000. The Asse mine was used as a demonstration facility (1965–1978) and as an R&D facility until 1997 [5]. (salt)
Japan	Crystalline and sedimentary rock; current repository design strategy focuses on plutonic rocks, and Pre-Neogene and Neogene sedimentary rocks [6].	In the current repository design strategy, vitrified HLW in stainless steel containers is placed in a carbon steel overpack that is surrounded by compacted bentonite buffer [6].	In the current repository design strategy, the engineered barrier system is important.	HLW and transuranic (TRU) waste	Tono (granite) Mizunami (granite) Horonobe (sedimentary rock) An underground investigation facility in the candidate host rock is planned to be constructed during the detailed investigation stage of the site-selection process [7].
Republic of Korea	Granite	No decision has been made. A conceptual-level Korea Reference Disposal System was developed in the late 1990s. In that system, options were considered for the canisters, most likely to be made from copper. The canisters would be surrounded by bentonite.	In the conceptual-level reference design, the engineered barrier system was very important.	SNF and possibly pyroprocessed HLW	KAERI Underground Research Tunnel in Daejeon (granite)

Technical Attributes

Country	Requirements for Defense in Depth	Long-Term Health and Safety Requirements	Methodology for Demonstrating Compliance with Postclosure Standards	Requirements for Retrievability
Germany	Safety after repository closure must be secured through a robust, graduated barrier system that fulfills its functions in a passive, maintenance-free manner and continues to ensure adequate functionality even if individual barriers fail to develop their full effect.	0.01 mSv/year for probable developments 0.1 mSv/year for less probable developments Compliance period is 1 million years	Deterministic calculations must be carried out on the basis of modeling as realistically as possible using, for example, median values as input parameters. Sensitivity analyses must be carried out to highlight the influence of uncertainties. The objective of these analyses is to demonstrate that no fluid paths develop during the compliance period.	The repository design must provide for retrieval of waste during the operational period and the possibility of recovery for 500 years after repository closure (Site Selection Act).
Japan	No decision has been made.	No decision has been made. The current analysis assumes a dose constraint value of 0.01 mSv/year for base scenario and 0.3 mSv/year for variant scenario [6]. For the low-probability perturbation and human intrusion scenarios, the dose constraint was assumed to range from 0.02-0.1 mSv/year for the first year and 0.001-0.02 mSv/year thereafter. The risk constraint was assumed to be 10^{-5}/year for the scenarios considered.	No decision has been made. A generic performance assessment as part of the NUMO Safety Case included [6, 8]: • Crystalline rock, Neogene sedimentary rock and Pre-Neogene sedimentary rock as candidate host rocks • Risk-based probabilistic approach that includes uncertainty analyses • Scenarios such as base, variant, low-probability perturbation and human intrusion	Retrievability should be ensured until closure of the repository [6].
Republic of Korea	Safety philosophy includes defense in depth and some degree of redundancy in multi-barrier function.	The radiation dose for the representative person in a single scenario, including a low-probability natural phenomenon and human intrusion, should not exceed 10 mSv/year. The risk for the representative person resulting from radiation exposure in the scenario that includes both natural phenomena and human intrusion should not exceed 10^{-6}/year.	The postclosure performance assessment should include scenarios that consider natural phenomena such as earthquakes and floods and human intrusion for a minimum of 10,000 years. If the predicted risk does not reach its maximum value within 10,000 years, analyses should confirm that release rates will not increase significantly after this period.	No decision has been made, but in the conceptual-level Korea Reference Disposal System, waste packages had to be retrievable for an indeterminate period.

Technical Attributes

Country	Status of Repository Site-Selection Process	Anticipated Start of Repository Operations
Germany	The site-selection process was initiated in September 2017 [4]. As part of the first phase in the site-selection process, 90 potential "sub-areas" in claystone, salt, and crystalline host rocks were identified in September 2020. The site-selection procedure should be concluded by 2031.	No decision has been made.
Japan	Two municipalities Kamoenai village in Hokkaido prefecture and Suttu town in Hokkaido prefecture have responded to solicitation for a literature survey, which is the first stage in the site-selection process [9, 10]. The implementer plans to complete the site-selection process before 2030 [10].	The implementer plans to start repository operations before 2040 [11].
Republic of Korea	No specific schedule for beginning to site an HLW/SNF repository has been established. Preliminary site-selection activities have been in progress since 2016 [12]. The site-selection process is planned to be completed in 2028.	Though the national policy for geological disposal is not decided, the repository site is to be operational in 2053 [11].

References for Germany, Japan, and Republic of Korea:

1. Bundesgesellschaft für Endlagerung (BGE). 2022. "Stakeholders and tasks." Accessed January 20, 2022. https://www.bge.de/en/sitesearch/stakeholders-and-tasks/.
2. Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit und Verbraucherschutz (BMUV) [Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection]. 2013. "Repository Site Selection Act – StandAG." https://www.bmuv.de/en/law/repository-site-selection-act-standag. (Accessed January 20, 2022.)
3. Nuclear Engineering International. 2020. "Japan's Rokkasho reprocessing plant postponed again." Nuclear Engineering International Magazine, August 27, 2020. https://www.neimagazine.com/news/newsjapans-rokkasho-reprocessing-plant-postponed-again-8105722. (Accessed January 20, 2022.)
4. BGE. 2020. Sub-areas Interim Report pursuant to Section 13 StandAG. Peine, Germany: BGE. https://www.bge.de/fileadmin/user_upload/Standortsuche/Wesentliche_Unterlagen/Zwischenbericht_Teilgebiete/Zwischenbericht_Teilgebiete_-_Englische_Fassung_barrierefrei.pdf. (Accessed January 20, 2022.)
5. Nuclear Energy Agency (NEA). 2013. Underground Research Laboratories. Washington, DC: NEA. https://www.oecd-nea.org/rwm/reports/2013/78122-rwm-url-brochure.pdf. (Accessed January 20, 2022.)
6. Nuclear Waste Management Organization of Japan (NUMO). 2021. The NUMO Pre-siting SDM-based Safety Case. NUMO-TR-21-01. Tokyo, Japan: NUMO. https://www.numo.or.jp/technology/technical_report/pdf/NUMO-TR21-01_rev220222.pdf. (Accessed April 20, 2022.)
7. NUMO. 2016. The Underground Investigation Facility (UIF) concept in NUMO's program. NUMO-TR-15-02. Tokyo, Japan: NUMO. https://www.numo.or.jp/en/reports/pdf/TR-15-02.pdf. (Accessed January 20, 2022.)
8. NUMO. 2019. Report of the Special Review Committee on the NUMO safety case. Tokyo, Japan: NUMO. https://www.numo.or.jp/en/what/pdf/The_review_of_the_NUMO_safety_case.pdf. (Accessed January 20, 2022.)
9. NUMO. 2020. "Acceptance by Kamoenai village of proposal for Literature Survey." Accessed January 20, 2022. https://www.numo.or.jp/en/what/topics_201009_2.html.
10. NUMO. 2020. "Receipt of application for Literature Survey from Suttu town in Hokkaido." Accessed January 20, 2022. https://www.numo.or.jp/en/what/topics_201009_1.html.
11. NUMO. 2020. "Japanese Geological Disposal Program." Accessed January 20, 2022. https://www.numo.or.jp/en/jigyou/new_eng_tab01.html.
12. NEA. 2021. *Strategies and Considerations for the Back End of the Fuel Cycle.* NEA. No. 7469. Washington, DC: NEA. https://www.oecd-nea.org/upload/docs/application/pdf/2021-02/7469_best_report_2021-02-19_17-42-24_447.pdf. (Accessed January 20, 2022.)

Spain, Sweden, Switzerland

Institutional Arrangements

Country	Legislation Specific to Radioactive Waste Management	Implementing Organization	Independent Regulator	Independent Technical/ Program Oversight	Dedicated Funding Source for Repository Development
Spain	Nuclear Waste Policy Nuclear Energy Act, Law 25/1965, 1968 Law 15/1980 Royal Decree 1522/1984 of July 14 Royal Decree 102/2014 transposing EU Directive	Spanish Radioactive Waste Management Agency (Empresa Nacional de Residuos Radiactivos, S.A. [Enresa]) (public, non-profit organization)	Nuclear Safety Council (Consejo de Seguridad Nuclear [CSN]) The Ministry of Energy, Tourism and the Digital Agenda, legally makes the final decision but cannot overturn the CSN's report if it is negative or conditional.	None	Nuclear Decommissioning Fund is paid by the waste producers (covers both decommissioning nuclear power plants and radioactive waste management).
Sweden	Act on Nuclear Activities (1984, as amended) Radiation Protection Act (1988, as amended) Environmental Code (1998)	Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB [SKB]) (private corporation formed by the owners of nuclear power plants)	Swedish Radiation Safety Authority (Strålsäker-hetsmyndigheten [SSM]), within the Ministry of the Environment	Swedish National Council for Nuclear Waste (Kärnavfallsrådet) (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 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	Nuclear Energy Act (2003, as amended) Environmental Protection Act (1983) Radiological Protection Act (1991) Radiological Protection Ordinance (1994, as amended) Ordinance on the Collection of Radioactive Waste (2002, as amended) Nuclear Energy Ordinance (2004) Nuclear Safety Inspectorate Act (2007) Ordinance on Decommissioning and Waste Management Fund (2007)	National Cooperative for the Disposal of Radioactive Waste (Nationale Genossenschaft für die Lagerung radioaktiver Abfälle [Nagra]) (a public/private consortium of radioactive waste producers, including all the owners of nuclear power plants and the Federal Government)	Federal Nuclear Safety Inspectorate (Eidgenössisches Nuklearsicherheitsinspektorat [ENSI])	Swiss Federal Nuclear Safety Commission (advises Federal Council, Federal Department of Environment, Transport, Energy, and Communications, and regulator) Interdepartmental Working Group on Radioactive Waste Management prepares technical and political documents for governmental decisions on radioactive waste management [1]. Expert Group on Radioactive Waste Disposal advises regulator on geological aspects of radioactive waste disposal [1].	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 Nagra are paid for annually by the nuclear power plant owners.

Institutional Arrangements

Country	Regulations and Decrees Applicable to Licensing a DGR			Formal Legislative/Executive Approvals Required for Developing a DGR		
	Site Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site Selection	Facility Constructions and Operations
Spain	No decision has been made for an HLW/SNF repository.	Royal Decree 1/2008 Law 21/2013 on Environmental Assessment	Royal Decree 102/2014 on Safe and Responsible Management of Spent Nuclear Fuel and High-Level Radioactive Waste Nuclear Safety Council Regulation on Nuclear and Radioactive Facilities	With the transposition of EU Directive 2011/70 in Royal Decree 102/2014, the implementer proposed that deep-mined, geologic disposal be adopted.	No decision has been made for HLW/SNF.	No decision has been made for HLW/SNF.
Sweden	None	The Environmental Impact Assessment process is consistent with directives from the European Union.	Swedish Radiation Safety Authority Regulations relevant to health and safety protection include SSMFS 2008:37, 2008:21, and 2021:7.	In 1983, the Government decided that the Kärnbränslesäkerhet, nuclear fuel safety (KBS-3) approach formed an acceptable basis for the implementer to use in its plans for developing a repository.	In 2009, Forsmark site located in the municipality of Östhammar was approved by the Government.	Based on the review of the regulator and the Land and Environmental Court, the Government announced its approval of the license to construct a DGR in January 2022 [2]. The regulator's approval is required prior to trial operation and routine operation phases of the repository.
Switzerland	The Sectoral Plan, approved by the Federal Council in 2008, contains the requirements for repository site selection.	Environmental Protection Act (1983) and associated ordinances	Radiological Protection Ordinance Federal Nuclear Safety Inspectorate Protection Objectives for the Disposal of Radioactive Waste Guideline ENSI G03 (2009, 2020) replaces HSK-R-21 (1993).	Nuclear Energy Acts of 1959 and 2003	Federal Council (i.e., Federal Government) approval is required at the end of each stage in the three-stage site-selection process [1].	Construction and operating licenses are granted by Federal Department of Environment, Transport, Energy, and Communications. Federal Council grants the general license, which must be approved by the Parliament and is subject to a national referendum [1].

Institutional Arrangements

	Interactions with Local Jurisdictions			
Country	Local Veto	Limitations on Local Veto	Benefits to Be Provided to Local Community for Accepting a Facility	Explicit Adoption of a Staged Decision-Making Process
Spain	No decision has been made for an HLW/SNF repository. The process that led to siting the Centralized Temporary Storage facility required voluntary participation by local communities.	No decision has been made.	No decision has been made.	No decision has been made for an HLW/SNF repository.
Sweden	Local community can veto the choice of a site.	National override of veto can only occur if there is no alternative location for the repository in a community more willing to accept it.	An "added benefits" agreement was negotiated between Östhammar, the community selected for the repository, and Oskarshamn, the community not selected.	A license for a DGR for SNF will be granted in several steps. The first step involves the Government's license to construct, possess, and operate the repository. In addition, the regulator's authorization is required to start construction for trial and routine operations and for closure.
Switzerland	None, although informal participation and formal consultations are required at all stages of the Sectoral Plan.	Not applicable	The guidelines for negotiations for compensation allow individuals, cantons, and municipalities located in the siting region to initiate the negotiation process for compensation when the site selection is finalized [3]. The amount of compensation will depend on the cost studies and will be paid from the Decommissioning and Disposal Fund.	The Sectoral Plan contains three stages. Each stage needs to be approved by the Federal Council.

Technical Attributes

Country	Operating Nuclear Reactors/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a DGR	Centralized Interim Storage Facility Established
Spain	7 nuclear reactors (7.1 GWe)	Some commercial SNF from the Vandellós I plant was reprocessed at La Hague. Additional commercial SNF from the Santa María de Garoña and Zorita plants was reprocessed at Sellafield. Current national policy does not contemplate any additional reprocessing.	No decision has been made.	A site for the Centralized Temporary Storage facility, Villar de Cañas, was approved in 2011. A license to construct the facility was submitted to the Spanish Nuclear Safety Council in 2014. However, the project was suspended in July 2018 by the Government [4].
Sweden	6 nuclear reactors (6.8 GWe)	No. Although some commercial SNF have been reprocessed in France and the United Kingdom, no vitrified waste was returned to Sweden.	Waste is planned to be transported to the Östhammar site by a specially designed ship, the Sigrid.	Yes, the Central Interim Storage Facility for Spent Nuclear Fuel (Clab) in Oskarshamn was commissioned in 1985.
Switzerland	4 nuclear reactors (2.9 GWe)	Commercial SNF was reprocessed in France and the United Kingdom until a 10-year moratorium on reprocessing went into effect in 2006 [1]. This moratorium was further extended for another four years. After 2018, reprocessing of SNF assemblies was prohibited (Nuclear Energy Act, Article 9). For SNF that was reprocessed, all the resulting vitrified HLW has been packaged and returned to Switzerland.	Road and rail transport options are being considered by the implementer [5].	The Central Storage Facility (ZWILAG) in Würenlingen, near the Beznau Nuclear Power Plant, stores HLW and SNF.

Technical Attributes

Country	Geologic Environments Considered or Investigated for a DGR	Engineered Barrier System: Design	Engineered Barrier System: Importance to Safety Case	Waste Forms Authorized to be Disposed of in a DGR	Underground Research Laboratories
Spain	Granite, clay, and salt No geological environments are currently under consideration.	No decision has been made.	No decision has been made.	HLW, SNF, and Special Waste	None
Sweden	Granite*	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	SNF	Construction of the Äspö Hard Rock Laboratory in Oskarshamn began in 1990 and was completed in 1995. (granite)
Switzerland	Clay* and granite	The current disposal concept envisions that vitrified HLW and commercial SNF (pellet form) are packed in steel canisters [6]. These canisters are then placed on bentonite pedestals in the emplacement drifts and backfilled with granular bentonite material.	Relatively unimportant compared to the host rock (Opalinus Clay).	SNF and HLW [1]	Mont Terri rock laboratory in the canton of Jura (clay) and Grimsel Test Site in the canton of Berne (granite)

*Host rock for the selected (Sweden) and potential (Switzerland) DGR.

Technical Attributes

Country	Requirements for Defense in Depth	Long-Term Health and Safety Requirements	Methodology for Demonstrating Compliance with Postclosure Standards	Requirements for Retrievability
Spain	No decision has been made for HLW/SNF repository.	No decision has been made for HLW/SNF repository.	No decision has been made for HLW/SNF repository.	No decision has been made for HLW/SNF repository.
Sweden	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.	Per the regulation SSMFS 2008:37, the risk of harmful effects after closure does not exceed 10^{-6}/year for a representative individual in the group exposed to the greatest risk. The risk analysis should be carried out for a minimum of 100,000 years or the period of a glaciation cycle and can extend up to a maximum duration of 1 million years.	The regulations do not prescribe a specific methodology for demonstrating compliance. Both deterministic and probabilistic approaches can be used. Per the regulations, three types of scenarios are to be evaluated: (1) Main scenario—based on the probable evolution of the external conditions using realistic or pessimistic assumptions. (2) Less probable scenarios—prepared for evaluation of uncertainties; include variations on the main scenario with alternative sequences of events, such as human intrusion that could damage the barriers. (3) Residual scenarios—include sequences of events and conditions that illustrate the significance of individual barriers and barrier functions. The scenarios should also account for climate evolution and corresponding biosphere conditions and exposure pathways.	While there are no regulatory requirements for retrievability, measures for retrieving waste during operations and postclosure can be implemented.
Switzerland	The regulations require that the long-term safety of a repository shall be ensured by a system of multiple passive safety barriers.	Dose constraint is 0.1 millisievert (mSv)/year and the risk constraint is 10^{-5}/year for expected scenarios including low-probability events [7]. For the inadvertent human intrusion scenario, if the estimated dose is in the range of 1–20 mSv, then efforts must be made to reduce the probability of intrusion or to limit its consequences by optimizing the design of the facility. Complete containment is required for 1,000 years. The regulations require safety assessments for up to 1 million years.	Compliance must be demonstrated using the safety case for the following phases: [7] (a) Operational Phase: The safety case should be based on safety assessments for normal and accident scenarios for underground repository and above-ground surface facilities. (b) Postclosure Phase: The safety case should be based on comprehensive safety assessments that consider both quantitative and qualitative aspects accounting for impact of construction and operation on long-term safety. The safety assessment should include several aspects such as evolution of both engineered and natural barriers, scenario analyses including changes to climate and biosphere conditions, systematic sensitivity and uncertainty analyses, and justification for assumptions and computer models used.	The design of the repository must accommodate the retrieval of canisters without "undue effort" until closure [7]. Retrieval or partial retrieval of waste must be possible if the safety of repository is compromised and the barriers cannot be repaired.

Technical Attributes

Country	Status of Repository Site-Selection Process	Anticipated Start of Repository Operations
Spain	The site-selection process is planned to start in 2023 [8].	Repository operations are expected to start in 2063 [8].
Sweden	A site in the municipality of Östhammar was selected in 2009.	Pending regulatory approvals, the implementer expects to start the repository operations sometime in the 2030s [9].
Switzerland	The implementer recommended the regions of Jura Ost and Zürich Nordost as part of the second stage of the site-selection process. Both are in Opalinus Clay and are in northern Switzerland [1]. In its review, the regulator recommended including Nördlich Lägern area as an additional siting region to be investigated in the third stage of the site-selection process. The Federal Council approved the three siting regions to be investigated further as part of the third and final stage of the site-selection process. The implementer is expected to announce the location of DGR in 2022 and submit a license application by 2024.	Repository operations are expected to start in 2060 [1].

References for Spain, Sweden, and Switzerland:

1. Eidgenössisches Nuklearsicherheitsinspektorat (ENSI). 2020. *Implementation of the Obligations of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.* Brugg, Switzerland: ENSI. https://www.ensi.ch/de/wp-content/uploads/sites/2/2020/10/Joint_Convention-Seventh_national_report-Switzerland_2020_web.pdf. (Accessed January 20, 2022.)
2. Ministry of Environment. 2022. "The government allows final repository of spent nuclear fuel in Forsmark." Ministry of Environment press release, January 27, 2022. On the Ministry of Environment website, accessed January 27, 2022. https://www.regeringen.se/pressmeddelanden/2022/01/regeringen-tillater-slutforvar-av-anvant-karnbransle-i-forsmark/.
3. Bundesamt für Energie (BFE). 2021. "Fact Sheet - Benefits in the sectoral plan for deep geological repositories." https://www.bfe.admin.ch/bfe/de/home/versorgung/kernenergie/radioaktive-abfaelle/sachplan-geologische-tiefenlager.exturl.html/aHR0cHM6Ly9wdWJkYi5iZmUuYWRtaW4uY2gvZGUvcHVibGljYX/Rpb24vZG93bmxvYWQvOTc5Nw==.html. (Accessed January 20, 2022.)
4. Empresa Nacional de Residuos Radiactivos, S.A. (Enresa). 2020. *Directors Report.* Madrid, Spain: Enresa. https://www.enresa.es/eng/index/about-enresa/publications/category/9-institutional?download=139:annual-report-2020. (Accessed on January 20, 2022.)
5. Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (Nagra). "Safe transport of radioactive waste – today and in the future." https://www.nagra.ch/en/safetransportofradioactivewaste. (Accessed on January 20, 2022.)
6. Nagra. "Multiple barriers provide safety." Accessed January 20, 2022. https://www.nagra.ch/en/multiple-barriers-provide-safety.
7. ENSI. 2020. *Deep Geological Repositories – Guideline for Swiss Nuclear Installations.* ENSI G03. Brugg, Switzerland: ENSI. https://www.ensi.ch/en/wp-content/uploads/sites/5/2021/11/ENSI-G03_E_Edition_2020-12_web-1.pdf. (Accessed March 25, 2022.)
8. International Atomic Energy Agency. 2017. *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management - Sixth Spanish National Report.* Vienna, Austria: International Atomic Energy Agency. https://www.iaea.org/sites/default/files/national_report_of_spain_for_the_6th_review_meeting_-_english.pdf. (Accessed March 22, 2022.)
9. Svensk Kärnbränslehantering AB (SKB). 2022. "The Government approves SKB's final repository system."*SKB News,* January 27, 2022. https://www.skb.com/news/the-government-approves-skbs-final-repository-system/. (Accessed January 27, 2022.)

United Kingdom

Institutional Arrangements

Country	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) Infrastructure Planning (Radioactive Waste Geological Disposal Facilities) Order 2015 Environmental Authorisations Regulations for Scotland (2018)	Nuclear Waste Services (NWS), part of the Nuclear Decommissioning Authority group† (public sector organization sponsored by the Department for Business, Energy & Industrial Strategy; for some aspects of its functions, it is also responsible to Scottish Ministers)	Environment Agencies (England, Scotland, and Wales) Office for Nuclear Regulation	Committee on Radioactive Waste Management (CoRWM) (advises Government and ministers of the devolved administrations of Scotland, Wales, and Northern Ireland) and the implementer	None Government will pay the costs of managing legacy waste. Government policy is that owners and operators of new nuclear power plants set aside funds to cover their full share of waste management and disposal costs.

*In the United Kingdom, the policy for management of high-activity waste, which includes high-level radioactive waste (HLW) and millisievert (mSv), is set separately for England, Wales, and Scotland [1]. The Scottish Government's policy for long-term management is based on near-surface facilities. The Scottish policy excludes HLW as HLW is not accumulated in Scotland and SNF and other nuclear materials currently classified as waste are transferred to Sellafield for reprocessing. Northern Ireland does not have its own radioactive waste policy. There are no plans to site a repository in Northern Ireland.

† Nuclear Waste Services was launched in January 2022 and integrates the Low Level Waste Repository, Radioactive Waste Management, and the Nuclear Decommissioning Authority (NDA) group's Integrated Waste Management Programme [2].

Institutional Arrangements

Country	Regulations and Decrees Applicable to Licensing a DGR			Formal Legislative/Executive Approvals Required for Developing a DGR		
	Site Selection	Environmental Impact Assessment	Health and Safety Protection	Selection of Waste Management Option	Site Selection	Facility Constructions and Operations
United Kingdom	In England and Wales, the policy was updated to include a consent-based approach for siting based on close partnership with communities [1].	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) Implementing Geological Disposal – Working with Communities [3] Geological Disposal of Higher Activity Radioactive Waste: Working with Communities [4] Scotland's Higher Activity Radioactive Waste Policy [5]	Government must ultimately approve the site. Before the implementer applies for construction authorization for a repository, the local community must demonstrate its willingness to host a repository (Test of Public Support) [1].	After authorization by the Environment Agency, planning permission/development consent, and licensing by the Office of Nuclear Regulation, no further action is required.

Institutional Arrangements

Country	Interactions with Local Jurisdictions			
	Local Veto	Limitations on Local Veto	Benefits to Be Provided to Local Community for Accepting a Facility	Explicit Adoption of a Staged Decision-Making Process
United Kingdom	In England and Wales, before the implementer applies for construction authorization for a repository, there must be a Test of Public Support by the local community to demonstrate it is willing to host a repository [1]. If the result of the Test of Public Support is not positive, the siting process will cease in that community.	In England and Wales, communities can choose to withdraw from the siting process at any time up until the Test of Public Support is taken (Right of Withdrawal) [1].	Early investment is provided to communities engaged in the siting process. This payment can range from £1 million annually and can be increased to £2.5 million later on for each community [1].	The licensing and permitting process involves a staged authorization process. Decisions by the local communities at specific stages such as "Test of Public Support" are included as part of community engagement [3].

Technical Attributes

Country	Operating Nuclear Reactors/ Generating Capacity	Reprocessing Included in Fuel Cycle	Transportation System in Place to Move SNF/HLW to a DGR	Centralized Interim Storage Facility Established
United Kingdom	11 nuclear reactors (7.8 GWe) 2 nuclear reactors are under construction (3.2 GWe).	Reprocessing continues at Sellafield and is expected to be completed by 2022, and the plant will be decommissioned [6]. 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.	No decision has been made. The implementer is considering transportation using road, rail or sea [7].	Yes, established at Sellafield for HLW and SNF

Technical Attributes

Country	Geologic Environments Considered or Investigated for a DGR	Engineered Barrier System		Waste Forms Authorized to Be Disposed of in a DGR	Underground Research Laboratories
		Design	Importance to Safety Case		
United Kingdom	No decision has been made. The implementer is considering three generic host rock types—evaporites (e.g., salt), higher strength rock (e.g., igneous or sedimentary), and lower strength sedimentary rocks (e.g., clays and mudstones) [7].	No decision has been made. The implementer is considering bentonite clay and cementitious materials as options for buffer and backfill in the engineered barrier system [7].	No decision has been made.	HLW; long-lived, intermediate-level radioactive waste; and low-level waste are not suitable for near-surface disposal. SNF and some nuclear materials (separated plutonium and uranium) are not currently classified as waste [1]. However, they can be declared as waste in the future, if necessary.*	None

*The implementer has included a defined volume of SNF and nuclear materials in its planning assumptions for disposal.

Technical Attributes

Country	Requirements for Defense in Depth	Long-Term Health and Safety Requirements	Methodology for Demonstrating Compliance with Postclosure Standards	Requirements for Retrievability
United Kingdom	Required based on regulatory guidance [8]	Regulatory guidance specifies [8]: • A dose constraint of 0.5 mSv/year for the operational period. • 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. A compliance period is not specified for the postclosure phase [8].	Guidance does not prescribe a specific methodology but states that the performance assessment should consider quantifiable uncertainties and variant scenarios [8]. The human intrusion scenario should be included in the analysis. The implementer has developed generic performance assessment models for the three host rocks being evaluated [9]. These models, using the probabilistic approach, include the base case and variant (e.g., human intrusion, disruptive events) scenarios.	Guidance does not require the waste to be retrievable [8]. However, if provisions for retrievability are included in the repository design, these provisions should not affect the safety case.

Technical Attributes

Country	Status of Repository Site-Selection Process	Anticipated Start of Repository Operations
United Kingdom	The community of Theddlethorpe has established a working group, which is the first step in the site-selection process [10]. The communities of Allerdale, Mid Copeland, and South Copeland have formed community partnerships, which is the second step in the site-selection process [11, 12, 13]. The implementer expects that it will take 5–20 years to complete the site-selection process after establishing a community partnership [14].	No decision has been made.

References for United Kingdom:

1. Department for Business, Energy and Industrial Strategy (BEIS). 2020. *The United Kingdom's National Report on Compliance with the Obligations of the Joint Convention on the Safety of Spent Fuel and on the Safety of Radioactive Waste Management.* London, UK: BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1006999/The_United_Kingdom_s_Seventh_National_Report_on_Compliance_with_the_Obligations_of_the_Joint_Convention.pdf. (Accessed January 20, 2022.)
2. Nuclear Waste Services (NWS). 2022. *Securing a safer future for us all Introducing Nuclear Waste Services.* Cumbria, UK: Nuclear Waste Services. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1051260/NWS_strategy_document_ACC.pdf. (Accessed January 31, 2022.)
3. BEIS. 2018. *Implementing Geological Disposal–Working with Communities. An updated framework for the long-term management of higher activity radioactive waste.* December. London, UK: BEIS. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/766643/Implementing_Geological_Disposal_-_Working_with_Communities.pdf. (Accessed on January 20, 2022.)
4. Welsh Government. 2019. *Geological Disposal of Higher Activity Radioactive Waste: Working with Communities*. Cardiff, Wales: Welsh Government. https://gov.wales/sites/default/files/publications/2019-04/geological-disposal-of-higher-activity-radioactive-waste-guidance-for-communities.pdf. (Accessed January 20, 2022.)
5. Scottish Government. 2011. *Scotland's Higher Activity Radioactive Waste Policy 2011.* Edinburgh, Scotland: Scottish Government. https://www.gov.scot/binaries/content/documents/govscot/publications/corporate-report/2011/01/scotlands-higher-activity-radioactive-waste-policy-2011/documents/0111419-pdf/0111419-pdf/govscot%3Adocument/0111419.pdf. (Accessed January 20, 2022.)
6. Nuclear Decommissioning Authority. 2021. *Draft Business Plan 1 April 2022 to 31 March 2025.* Cumbria, UK: Nuclear Decommissioning Authority. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1038688/Draft_Business_Plan_2022-2025_final.pdf. (Accessed January 20, 2022.)
7. Radioactive Waste Management (RWM). 2020. *Geological Disposal Science and Technology Plan 2020.* Oxford, UK: RWM. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/931865/Science_and_Technology_Plan_2020.pdf. (Accessed on January 20, 2022.)
8. Environment Agency and Northern Ireland Environment Agency. 2009. *Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation.* Bristol, UK: Environment Agency and Northern Ireland Environment Agency. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/296504/geho0209bpjm-e-e.pdf. (Accessed May 23, 2022.)
9. Vines, Sarah. 2021. "Environmental safety case models supporting geological disposal of the UK's radioactive waste." Presentation to the Nuclear Waste Technical Review Board at its November 3-4, 2021 meeting. https://www.nwtrb.gov/docs/default-source/meetings/2021/november/vines.pdf?sfvrsn=4. (Accessed January 20, 2022.)
10. RWM. 2021. "RWM welcomes formation of Theddlethorpe GDF Working Group." *RWM News,* October 12, 2021. https://www.gov.uk/government/news/rwm-welcomes-formation-of-theddlethorpe-gdf-working-group. (Accessed January 20, 2022.)

11. RWM. 2022. "Allerdale GDF Community Partnership forms." *RWM News,* January 18, 2022. https://www.gov.uk/government/news/allerdale-gdf-community-partnership-forms. (Accessed January 20, 2022.)

12. RWM. 2021. "RWM welcomes Mid Copeland taking next step in GDF process." *RWM News,* November 16, 2021. https://www.gov.uk/government/news/rwm-welcomes-mid-copeland-taking-next-step-in-gdf-process. (Accessed January 20, 2022.)

13. RWM. 2021. "Second GDF Community Partnership forms in Cumbria." *RWM News,* December 14, 2021. https://www.gov.uk/government/news/second-gdf-community-partnership-forms-in-cumbria. (Accessed January 20, 2022.)

14. RWM. 2020. *A Permanent Solution for Higher-Activity Radioactive Waste.* Oxford, UK: RWM. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/916682/A_Permanent_Solution_for_Higher_-_Activity_Radioactive_Waste.pdf. (Accessed on January 20, 2022.)

Acronyms

Andra	Agence nationale pour la gestion des déchets radioactifs (National Agency for Radioactive Waste Management), France
ASN	Autorité de sûreté nucléaire (Nuclear Safety Authority), France
BASE	Bundesamt für die Sicherheit der nuklearen Entsorgung (Federal Office for the Safety of Nuclear Waste Management), Germany
BGE	Bundesgesellschaft für Endlagerung mbH (Federal Company for Radioactive Waste Disposal), Germany
CAEA	China Atomic Energy Authority
CANDU	Canada deuterium uranium reactor
CNE	Commission nationale d'évaluation (National Review Board), France
CNNC	China National Nuclear Corporation
CNSC	Canadian Nuclear Safety Commission
CoRWM	Committee on Radioactive Waste Management, United Kingdom
CSN	Consejo de Seguridad Nuclear (Nuclear Safety Council), Spain
DGR	deep geologic repository
DOE	U.S. Department of Energy
Enresa	Empresa Nacional de Residuos Radiactivos, S.A. (Spanish Radioactive Waste Management Agency)
ENSI	Eidgenössisches Nuklearsicherheitsinspektorat (Federal Nuclear Safety Inspectorate), Switzerland
EPA	U.S. Environmental Protection Agency
ESK	Entsorgungskommission (Nuclear Waste Management Commission), Germany

FANC	Federaal Agentschap voor Nucleaire Controle (Federal Agency for Nuclear Control), Belgium
GWe	Gigawatts of electric power
HLW	high-level radioactive waste
IAEA	International Atomic Energy Agency
KBS	Kärnbränslesäkerhet (nuclear fuel safety)
KORAD	Korea Radioactive Waste Agency, Republic of Korea
MINETAD	Ministry of Energy, Tourism and Digital Agenda, Spain
MOTIE	Ministry of Trade, Industry and Energy, Republic of Korea
mSv	millisievert
Nagra	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle (National Cooperative for the Disposal of Radioactive Waste), Switzerland
NEA	Nuclear Energy Agency
NNSA	National Nuclear Safety Administration, China
NRA	Nuclear Regulation Authority, Japan
NRC	U.S. Nuclear Regulatory Commission
NSSC	Nuclear Safety and Security Commission, Republic of Korea
NUMO	Nuclear Waste Management Organization, Japan
NWMO	Nuclear Waste Management Organization, Canada
NWS	Nuclear Waste Services, United Kingdom
NWTRB	U.S. Nuclear Waste Technical Review Board
OECD	Organization for Economic Co-operation and Development
ONDRAF/NIRAS	Organisme national des déchets radioactifs et des matières fissiles/ Nationale Instelling voor Radioactief Afval en verrijkte Splijtstoffen (National Agency for Radioactive Waste and Enriched Fissile Materials), Belgium
R&D	research and development
RWM	Radioactive Waste Management, United Kingdom
SFOE	Swiss Federal Office of Energy
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)
SNF	spent nuclear fuel

SSM	Strålsäkerhetsmyndigheten (Swedish Radiation Safety Authority)
STUK	Säteilyturvakeskus (Radiation and Nuclear Safety Authority), Finland
TRU	transuranic

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 mudstone (claystone or siltstone) or shale that has hardened (i.e., indurated) via heat or pressure or introduction of a cementing material.

assessment, environmental impact An evaluation of radiological and non-radiological 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.

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

assessment, safety A quantitative analysis of the overall system performance where the performance measure is radiological impact or some other global measure of the impact on safety, both during repository operations and after repository closure.

Note: Most of these definitions have been taken from International Atomic Energy Agency (IAEA), 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 (American Geological Institute. 2011. Glossary of Geology, Fifth Edition, Revised, Alexandria, VA). The definitions of "safety assessment" and "safety case" were derived from the IAEA reports. (IAEA 2011. Geological Disposal Facilities for Radioactive Waste. Specific Safety Guide No. SSG-14. Vienna, Austria and IAEA. 2012. The Safety Case and Safety Assessment for the Disposal of Radioactive Waste. Specific Safety Guide No. SSG-23. Vienna, Austria.)

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.

buffer Any substance placed around a waste package in a repository to serve as an additional barrier to stabilize the surrounding environment; restrict the access of groundwater to the waste package; and reduce by sorption the rate of eventual radionuclide migration from the waste.

canister The container into which the waste form is placed for handling, transport, storage, and eventual disposal. For example, molten high-level waste glass would be poured into a specially designed canister where it would cool and solidify. The canister is normally a component of the waste package.

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. They contain minerals that are essentially hydrated aluminum silicates or occasionally hydrated magnesium silicates, with sodium, calcium, potassium, and magnesium cations. Clays differ greatly mineralogically and chemically and consequently in their physical properties. Because of their large specific surface areas, most of them have good sorption characteristics.

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 dispersion of radioactive substances.

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

decommissioning Administrative and technical actions taken to allow 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 radioactive materials, for which the term closure is used.

defense in depth 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 SNF as waste without reprocessing.

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 radiation dose or the equivalent radiation 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 disposal system that contribute to isolation of the waste from the human-accessible environment. Examples of engineered barriers include waste forms, waste packages, and seals with physical and chemical characteristics that significantly isolate the waste or decrease the mobility of radionuclides. *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 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 R&D activities, and all related radioactive waste management activities including decommissioning and waste disposal.

fuel cycle, once-through Refers to the fuel cycle option where SNF 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, which is no longer usable in its present form because of depletion of fissile material, buildup of poison, or radiation 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 solidifying 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 radioactive 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 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."

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 containers 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 closure of a repository and 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 The chemical or electrochemical treatment of SNF that can separate valuable or usable fissile materials, such as uranium and plutonium, from fission products and other waste materials in the fuel. The separated fissile material may be recycled and used in new applications, such as using the recovered uranium in the fabrication of new nuclear fuel.

risk A multi-attribute 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 maximum likelihood 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. It is measured in terms of probability per year.

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 (e.g., granite, gneiss, granodiorite, and migmatite), 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 rocks such as granite and volcanic rocks such as basalt.

rock, sedimentary A rock resulting from the consolidation of loose sediment that has accumulated in layers consisting of mechanically formed fragments of older rock transported from its source and deposited in water or a chemical rock (such as salt) formed by precipitation from solution.

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

safety case A collection of logic and evidence that demonstrates that a nuclear waste repository meets the performance requirements defined by the appropriate regulatory authorities. A safety case includes key results from the safety assessment. It also includes quantitative and qualitative supporting evidence and reasoning on (i) the robustness and reliability of the repository, (ii) its design and the rationale for the design choices made, and (iii) the quality and uncertainties of the safety assessment and underlying assumptions.

salt In geology, generally used to refer to naturally occurring halite (sodium chloride). The salt host rocks refer to a geological formation resulting from the evaporation of sea water. Salt formations occur as bedded or domal (salt dome) deposits. In a bedded formation, the salt is still in a similar shape as it was when deposited. A salt dome results from an uplift within a bedded salt formation.

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, and site confirmation.

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

spent nuclear fuel management All activities that relate to handling or storage of spent nuclear fuel.

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

storage Holding of spent nuclear fuel or 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 special underground laboratory for conducting in situ tests on waste repository system interactions under the full range of repository environment conditions.

vitrified waste Waste that has been incorporated into a glass or glass-like form. Vitrification is commonly applied to solidification of liquid high-level radioactive waste from reprocessing spent nuclear fuel. *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 radioactive (HLW) The following can be classified as high-level waste:

a) The radioactive liquid containing most of the fission products and actinides present in spent nuclear fuel, which forms the residue from the first solvent extraction cycle in reprocessing, and some of the associated waste streams
b) The liquid waste material following solidification
c) Spent fuel (if it is declared a waste)
d) 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 greater than 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 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.**

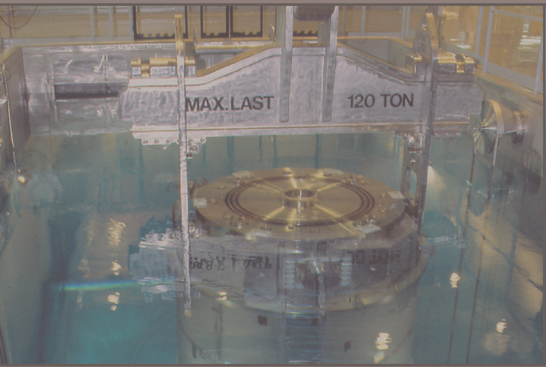
waste disposal *See* **disposal.**

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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