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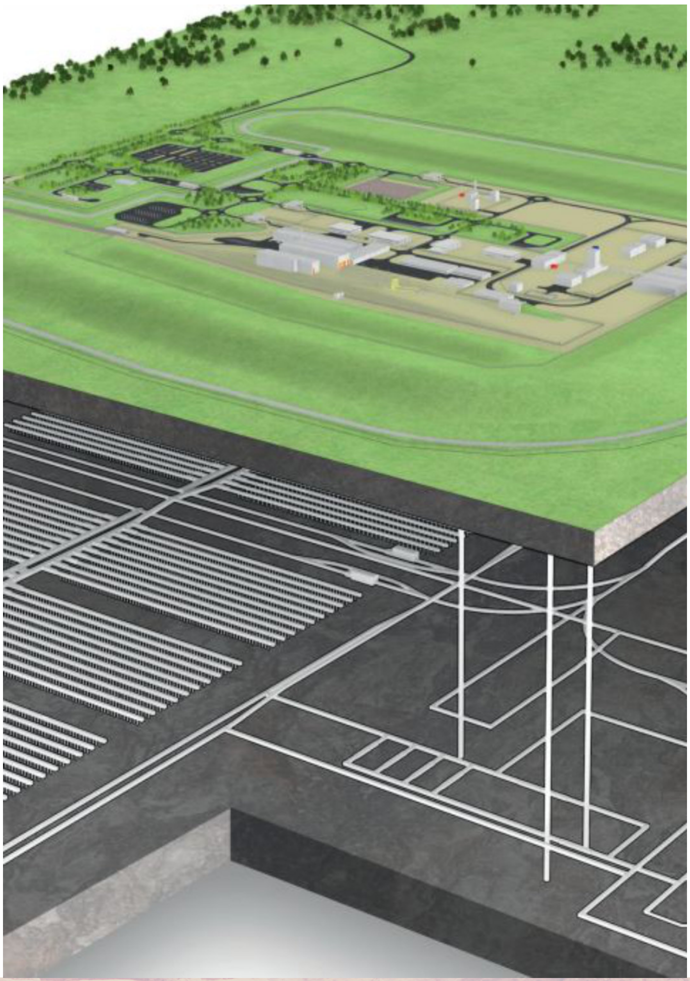
What is radioactive waste?

What is geological disposal?

How can geological disposal ensure the long-term safety of radioactive waste?

How will the UK select a site to dispose of radioactive waste?

The essential role of geoscience skills and knowledge



Geological Disposal of Radioactive Waste

A policy briefing note from the Geological Society of London

To find out more visit www.geolsoc.org.uk/gdrw or email policy@geolsoc.org.uk

Geological Disposal of Radioactive Waste

The implementation of geological disposal of radioactive waste has been the UK Government's adopted policy since 2008. The Geological Society has engaged with this policy area over the last 15 years by responding to Government inquiries and consultations, hosting technical meetings and conferences, and convening experts to offer independent guidance on geological matters. This briefing note outlines the ways in which geological expertise and geologists are essential for the disposal of radioactive waste.

What is radioactive waste?

Radioactive waste is used or spent radioactive material produced by the medical, industrial, defence, research, processing and power sectors (Figure 1), or non-radioactive material which has been contaminated through exposure to radioactive sources. As it decays, radioactive waste emits radiation which can have negative health and environmental effects if encountered at critical doses.

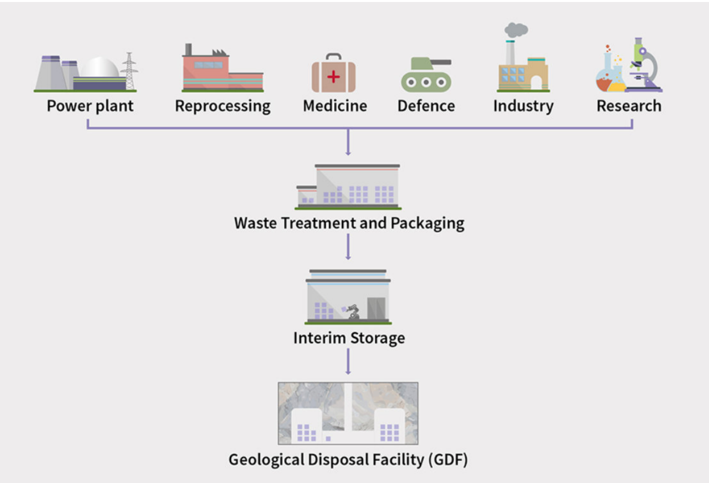


Figure 1 - Sources and management of radioactive waste in the UK. Source: UK Government.

Radioactivity is a natural phenomenon caused by the decay of atomically unstable material. The decay releases radioactive energy, or radiation. The rate at which this occurs (half-life) and the strength of radiation emitted (radioactivity) varies depending on the properties of the material and the characteristics of its decay (Figure 2).

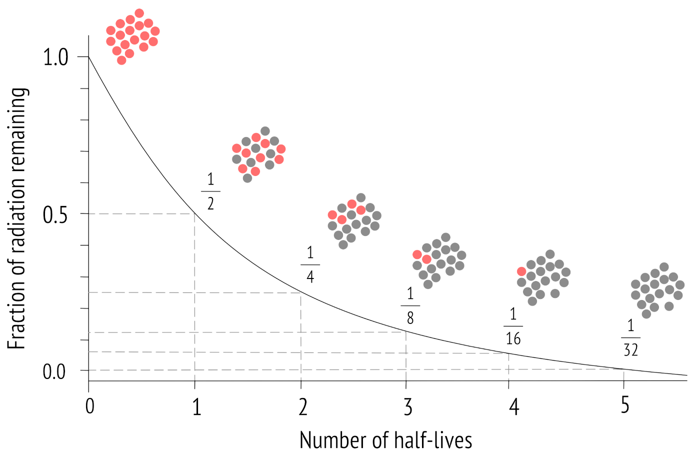


Figure 2 - Illustration of the decay of radioactive material and the 'half-life' concept. Adapted from © Andrew Frankoi, David Morrison, Sidney Wolff (Rice University), CC BY 4.0, Wikimedia Commons.

Many things we interact with on a daily basis - such as food, drink, our atmosphere and the rocks beneath our feet - emit low level radiation called background radiation. Due to its relatively low intensity, background radiation is not a safety concern in most areas of the UK[1], however waste material such as spent nuclear fuel does pose a safety risk if not properly managed. It is imperative that we process, package, store and manage our radioactive waste in a safe, efficient way for the long term to ensure we protect ourselves and our environment from its potential negative effects long into the future.

Radioactive waste is an overarching term for a large number of different waste streams, each containing various radionuclides with differing radiation levels and decay timeframes. It can be categorised in three groups: High Level Waste (HLW) Intermediate Level Waste (ILW) or Low Level Waste (LLW), depending on the level and type of radioactivity (Figure 3).

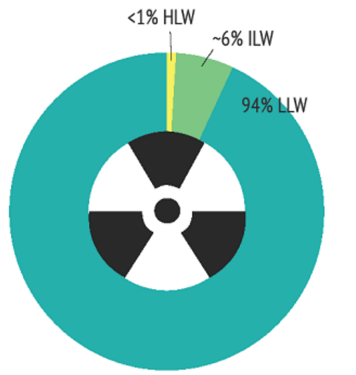


Figure 3 – Proportion of each type of radioactive waste generated in the UK by volume.
Data: www.ukinventory.nda.gov.uk.

Most of the waste produced in the UK (94% by volume) is LLW and is disposed of in surface repositories such as the LLW Repository in Cumbria, England or Dounreay in Caithness, Scotland. Surface or near-surface repositories isolate waste from the surrounding environment by storing it either a few metres below ground or in engineered facilities above ground. All waste with radioactivity above the LLW limit is classified as ILW or HLW and requires geological disposal to isolate it from the environment while it decays.

[1] In some areas of the UK, the levels of radon are above background due to the presence of rocks and minerals rich in Uranium-238 (radon's parent radionuclide). Whilst high levels of radon can be detrimental to human health, simple building remediation can reduce the levels where a threat exists. See 'UKradon' from Public Health England for more information: www.ukradon.org.

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Around 90% of the radioactive wastes produced in the UK come from the nuclear power sector, with the remaining 10% coming from the medical, industrial, research and defence sectors (Table 1). Most HLW is generated by the reprocessing of spent nuclear fuel, though the inventory for disposal includes some spent fuel that will remain once reprocessing ceases. As well as legacy waste - already listed in the inventory - there is a notable volume of radioactive material currently in use (or committed to use through policies or agreements in place) in the UK that will one day add to the inventory. There is also potential for the generation of waste from new nuclear projects which have not yet been decided upon – this quantity of waste is the most uncertain as it relies on decisions yet to be made. You can find out more information about the UK's existing radioactive waste at www.ukinventory.nda.gov.uk.

Geoscientists will...

- **Evaluate** – survey and assess a site to ensure that it has suitable characteristics to host a GDF
- **Monitor** – review the short- and long-term performance of the multi-barrier protection offered by the geology and the engineered barrier
- **Remediate** – minimise any environmental effects of the construction of a GDF to the surface or near surface
- **Predict** – model and estimate of the likely impacts of a GDF to the surface and subsurface by understanding subsurface behaviour and response to change

...to ensure the long-term security of a Geological Disposal Facility.

SECTOR	ACTIVITIES THAT GENERATE RADIOACTIVE WASTES	EXAMPLES OF THE NATURE OF RADIOACTIVE WASTE
MEDICAL	The manufacture, use and disposal of radioactive sources for diagnostics and radiopharmaceuticals.	• used sealed sources from hospitals • contaminated laboratory equipment and materials • other solid wastes such as swabs, vials, syringes, gloves and dressings • liquid wastes, such as mildly active washings from laundry treatment of protective clothing • waste radiopharmaceuticals
INDUSTRIAL	Sterilisation of equipment, examination of metal welds and joints, gauging the thickness of items, the manufacture of various devices such as smoke detectors; as tracers to assess the behaviour of liquid effluents.	• equipment • metal shavings • glassware • rubber gloves • paper tissue • used, sealed sources • liquids • steel containers or cans
RESEARCH	Research into nuclear energy generation, chemistry of radionuclides, nuclear and radiation physics, radioactive tracing in chemical, physical and biological processes, materials radiography.	• novel irradiated fuels, and high-activity liquid and solid wastes from their testing and reprocessing • sodium metal coolants and contaminated coolant circuits • mixed wastes that are due to be recovered from old disposals
DEFENCE	Operation, maintenance and decommissioning of nuclear powered submarines. Maintenance of the UK's strategic nuclear weapons capability, and clean-up of disused military sites.	• used filters and resins from submarine reactor operations, decontamination of pond water and liquid treatment • metallic reactor components from the development, testing and decommissioning of submarine reactors • depleted uranium ammunitions, contaminated targets and ground from weapons testing • contaminated land from the clean-up of disused military sites to make them available for reuse

Table 1 – An overview of radioactive waste generated by sectors other than nuclear power. Adapted from www.ukinventory.nda.gov.uk.

How is waste currently stored?

The UK has a ~60-year legacy of generating, processing, storing and disposing of radioactive waste. Even if no new nuclear power development occurs, the total volume of radioactive waste (both existing and projected) to be managed appropriately is estimated to be 4,560,000m^3 (Table 2). Currently, the majority of the UK's radioactive waste (133,000m^3) is managed between two facilities at Dounreay in Scotland and Sellafield in Cumbria, with the rest located at 30 sites around the UK (Figure 4). While short-term surface or near-surface storage of HLW and ILW at these sites is safe and well-regulated, the risks associated with continuing to manage these materials at or near the surface over the long term are greater than those arising from deep geological disposal. A geological disposal facility would provide additional protection from surface environmental processes (such as the long-term surface impacts of climate change) or unwanted human intervention.

WASTE TYPE	VOLUME (M^3)		
	Up to 2019	After 2019	Lifetime
HLW	2,150	-760	1,390
ILW	102,000	145,000	247,000
LLW	27,400	1,450,000	1,480,000
VLLW	1,040	2,830,000	2,830,000
TOTAL	133,000	4,420,000	4,560,000

Table 2 - The UK's 2019 radioactive waste inventory. Data: ukinventory.nda.gov.uk.

A geological disposal facility has been determined "the best available approach for the long-term management" of the UK's higher-level radioactive waste in a detailed review by the Committee on Radioactive Waste Management (CoRWM) for the Government, completed in 2006. This review evaluated the safety and feasibility of a long list of radioactive waste management options including disposal at sea, in ice sheets, or in outer space many of which were deemed unsafe or technically unachievable at the time of publication.

The Committee developed a short list of management options which were screened against a broad set of criteria to assess their suitability for the UK. Following this, CoRWM recommended that geological disposal is implemented, and that safe and secure storage is required in the interim. CoRWM also recommended a siting and development process based on community voluntarism and partnership. These recommendations were incorporated into a 2008 White Paper, 'Managing Radioactive Waste Safely', which sets out the Government's commitment to a geological disposal facility.

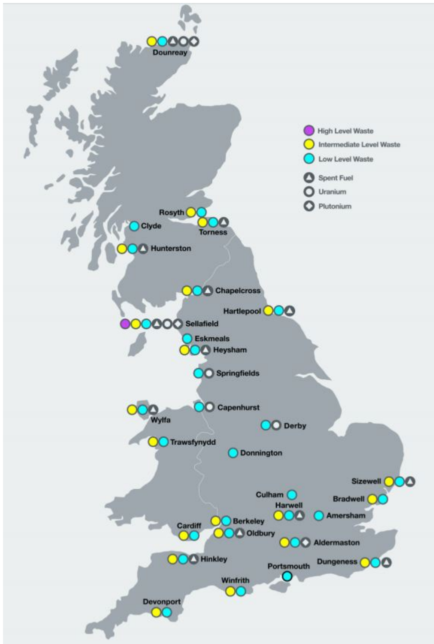

Figure 4 - Sites where radioactive waste and materials are currently stored. Source: UK Government White Paper: Implementing Geological Disposal (2014).

The UK Government reinforced this commitment in 2014 with its White Paper entitled 'Implementing Geological Disposal', which outlined the English policy framework for enacting geological disposal (joint with Northern Ireland). In 2019 the Welsh Government adopted their policy 'Geological disposal of radioactive waste: working with potential host communities', outlining their support for geological disposal of radioactive waste whilst offering specific guidelines for communicating with interested communities in Wales. Scotland set out its national policy on radioactive waste in 2007, following this with a specific policy for higher radioactivity waste in 2011 and an implementation strategy in 2016. Unlike the rest of the UK, current Scottish radioactive waste policy is to store higher-level waste in near-surface facilities, as close as possible to the location where the waste is generated, minimising transportation and maintaining retrievability.

What is geological disposal?

Geological disposal involves safely emplacing radioactive waste between 200 and 1,000m underground in an engineered geological disposal facility (GDF) where it can decay without releasing radiation to the surface environment (Figure 5). The waste is isolated from the surface by multiple physical barriers (both geological and constructed) which minimise the release of radioactivity. The multi-barrier disposal concept typically involves immobilising HLW in glass and packaging it in protective metal containers, or grouting ILW in cement and packaging it in steel or concrete, and then emplacing the packaged waste in the GDF, surrounded by bentonite clay (HLW) or cement (ILW) (Figure 6). Encapsulating the waste in glass or cement reduces its solubility; no liquid waste forms will be disposed.

Bentonite clay swells on interaction with groundwater in the subsurface, tightly sealing the metal HLW container in place. Over time, once the radioactivity of waste has significantly reduced due to natural decay, the engineered barriers may degrade and any remaining radioactivity may be released into the surrounding rock. The design of the engineered barriers can be tailored to complement the natural design characteristics of the rocks hosting the GDF in order to maximise containment of the radioactivity - meaning that a facility can be engineered to ensure safe disposal of radioactive waste in most geological settings. Ultimately, the geological barrier surrounding a GDF should retain and retard radionuclides when the engineered barrier eventually ceases to be effective.

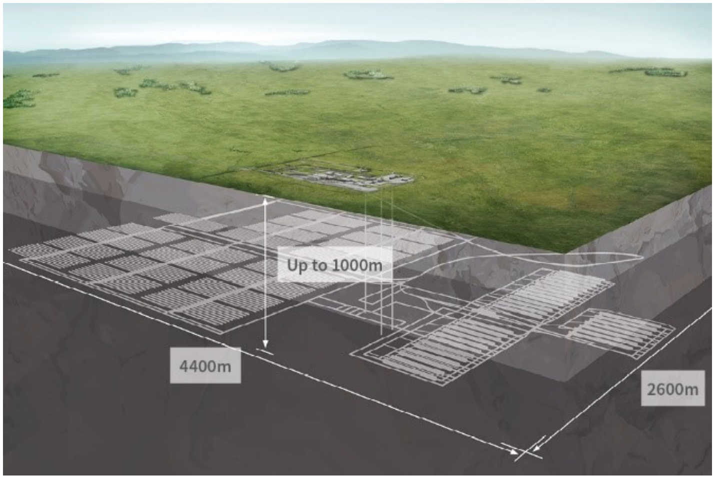

Figure 5 - Illustrative diagram of a geological disposal facility (GDF). Source: Radioactive Waste Management.

Why geological disposal?

Geological disposal provides long-term security for waste to naturally decay. A geological disposal facility offers an inert and effectively permanent environment in which waste can be disposed of for geological timescales, which are much greater than the timescales on which radioactive waste decays (>100,000 years). It is not envisaged that containers would ever need to be retrieved, though design and engineering will continue to consider the feasibility of retrieval during the development of a GDF should there be a compelling reason to do so. Once the facility is back-filled and sealed at the surface, no maintenance is required and importantly there is no further cost for management, meaning that future generations are not burdened with the management of waste that previous generations created. Underground, the waste is protected from uncertainties of the surface and near-surface environment, such as the impacts of climate change or unwanted human intervention. This minimises the risk to future generations from the impacts of our nuclear legacy in the UK. In a GDF, waste is additionally protected from political and societal change that could affect its security at the surface (e.g. terrorist actions, war, loss of institutional control, and severe environmental change).

How can geological disposal ensure long-term safety?

In a geological disposal facility the *in situ* geological and emplaced engineered barriers work together to ensure that the radioactive waste is contained and that migration of radiation to the surface via movement of fluid in the subsurface is minimised. The characteristics of the rocks hosting a geological disposal facility affect the design of the engineered components of the GDF as they offer complementary features to ensure containment.

By studying local-scale geological maps, data from boreholes and geophysical data geologists can broadly determine the characteristics that make an area suitable for a GDF. There have been over 40 years of collaborative international research in this area of geoscience, providing a sound and detailed foundation of knowledge on which to base the implementation of geological disposal. The volume of peer-reviewed and replicated research into this area increases the degree of confidence in any data and interpretive models used to understand the subsurface under geological disposal conditions, while underground rock laboratories (URLs) let geologists test the performance of disposal concepts in different rock types. URLs may also be used to improve understanding of the geology of particular candidate sites for a GDF and the engineered solutions most appropriate to them. The methods used to assess and monitor a GDF are well established and commonly used in many other industries including hydrogeological, geophysical and environmental geoscience.

In a national geological screening exercise undertaken by RWM and the British Geological Survey, subsurface characteristics throughout England, Wales and Northern Ireland were assessed broadly against five criteria to inform stakeholders on the possibility of there being a suitable geological setting for a GDF.

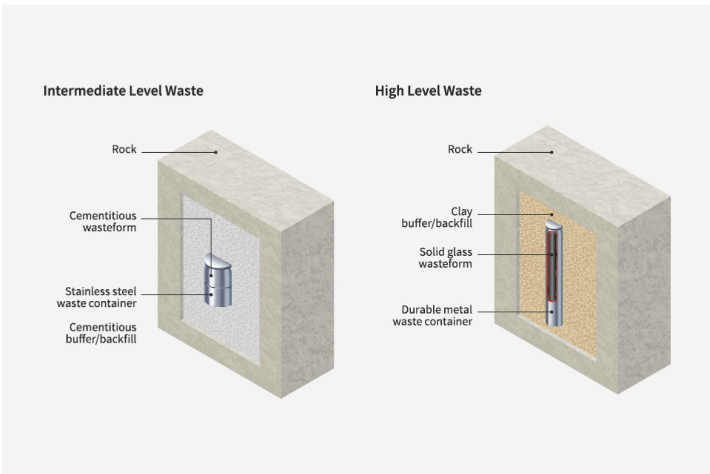

Figure 6 - Examples of a multi-barrier waste containment system. Source: Radioactive Waste Management.

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1. Rock type

The geology surrounding a GDF must be able to support the construction of underground infrastructure and should be geologically (tectonically) stable. Many types of rocks can provide these qualities, including high-strength igneous and metamorphic rocks such as granites, lower-strength sedimentary rocks such as mudstones, and evaporites such as rock salt deposits. The rocks hosting a GDF should have little to no groundwater movement, with slow and predictable groundwater movement in the rocks above the GDF, enhancing the geological barrier between the disposal facility and the surface.

2. Rock structure

Folds, faults and fractures can affect the size, shape, stability and permeability of rock units underground. To accommodate a GDF, the rock units must be of suitable size and shape to support the design of the underground facility, which can incorporate some flexibility depending on the nature of the rock structures. Structure can also either enhance or inhibit fluid flow in the subsurface, so the rocks must be carefully assessed to ensure that groundwater movement due to structures in any potential host rock would be minimal and well understood. Characterisation of properties such as response to thermal stress, plasticity, creep and fracturing are essential prior to construction in the subsurface.

3. Groundwater

It is imperative that the groundwater system is well characterised by hydrogeologists, as groundwater circulating between the surface and depth has the potential to transport dissolved radioactive material along the same path. This characterisation must include an assessment of the direction and magnitude of flow, the driving force(s) for flow, the existence of vertically separated flow, and any outflows. It is also key to understand the variability in groundwater chemistry, its effect on any engineered infrastructure underground, and its ability to dissolve, transport or retard radionuclides. The chemical environment in a GDF will be one of the factors that are considered in deciding on the most suitable material for waste canisters. Copper and stainless steel are being considered as canister materials, depending on the particular GDF concept and other factors. Corrosion of canisters is one of the processes that influence containment in the long term - for example, dissolved sulphide reacts with copper and a safety analysis ensures that geochemical conditions will limit the amount of sulphide in groundwaters that will come into contact with canisters. Groundwater present in clay-rich rocks - which does not circulate - can allow certain clay minerals to swell and offer an additional impermeable geological barrier preventing release of radioactivity. This property of swelling clays is also utilised in designing waste packaging, where an impermeable natural material such as the swelling clay 'bentonite' can be used to backfill waste canisters, sealing in radioactivity.

4. Surface processes

Natural events such as earthquakes, ice ages or sea level changes can have impacts on the physical and chemical conditions in the subsurface on timescales of 10,000 to 100,000 years. Increases in ice cover can elevate pressure in the subsurface substantially, sea level rise can impact groundwater levels, and earthquakes or tectonic processes can alter geological stability. Any GDF must be engineered to withstand the changes inflicted by these kinds of events on the subsurface conditions, as waste will need to be disposed of for >100,000 years.

5. Natural resources

The presence of valuable materials or other resources in the subsurface can complicate the siting of a GDF. Areas with a history of mineral extraction (such as coal mining) can have complex groundwater characteristics, which may affect an area's ability to host a GDF where minimal groundwater movement is required. Additionally, areas where there are reserves of natural resources such as minerals, metals, aggregates and hydrocarbons might be avoided to allow for the future possibility of exploratory drilling and extraction that could interfere with disposed material in a GDF.

The siting process

If a community wishes to find out more about their potential to host a GDF, a number of further investigative studies will be undertaken. These will include a groundwater survey and detailed consideration of additional local geological information. Should a community be willing, the geology be suited, and the more detailed investigations yield favourable results, then RWM will progress with additional data gathering to build the safety case for developing a GDF at that location. Construction of a GDF will only go ahead should RWM and the independent regulators be confident that the geology is sufficient to support the design and safety case for a facility. The safety case for such a facility will be built around RWM's six siting factors, three of which are closely linked to the geology of a site (safety, environment and engineering facility).

The siting, design, construction, operation and closure of a disposal facility all require geological expertise to ensure that they can be carried out safely. The environmental impact of any disposal facility will be monitored and minimised by conducting thorough site investigations which will establish baseline environmental conditions and detect any change taking place. Geoscientists will be integral to the lifecycle of a disposal facility from conceptualisation, planning, design, assessment, construction and monitoring, through to closure and site remediation. Many of the skills and technologies that will enable safe construction, provide environmental assurance, and ensure engineering feasibility are already widely used among other geoscientific industries, from petroleum and civil engineering to environmental compliance and remediation.

More information about the siting process can be found on the Radioactive Waste Management website: geologicaldisposal.campaign.gov.uk.
Or you can email the enquiries team directly at gdfenquiries@nda.gov.uk.

Geological Disposal of Radioactive Waste

What happens to radioactive waste in other countries?

Progress towards geological disposal in other national radioactive waste management programmes.

Europe

Finland, Sweden, France and Switzerland are in the process of developing GDFs for their radioactive waste. **Finland's** radioactive waste repository at Olkiluoto will be the first permanent disposal facility in the world, with construction starting in 2020 and an operational licence expected in 2025. Waste will be disposed of 400-450m underground in Precambrian migmatitic gneiss.

In **France**, waste will be deposited 500m underground in clay-rich sediment at the Cigéo facility at Bure, which was initially expected to be operational by 2025 but is currently delayed.

The **Belgian** government has yet to make a decision on the disposal of high-level radioactive wastes, though it has maintained long-running research to assess the potential of the Tertiary-age Boom Clay as a potential host rock.

In **Sweden**, radioactive waste will be disposed of in a repository within granitic and other crystalline rocks near Forsmark, with construction expected in the early 2020s.

In **Switzerland**, exploratory drilling is taking place in three potential siting regions with clay-rich rocks in northern Switzerland to find two sites suitable to host two disposal facilities, one for low- and intermediate-level wastes and one for high-level waste.

While plans for a deep geological disposal facility are developing in **the Netherlands**, their radioactive waste is stored in engineered facilities at the surface, as their high groundwater table makes shallow subsurface storage disposal unsuitable (even in the interim). A deep geological repository will be considered when the country has generated sufficient waste to warrant it, and construction in collaboration with another country is being considered.

North America

Canada is developing a deep geological repository for low- and intermediate-level wastes at Bruce at the edge of Lake Huron in Ontario. The repository will be located 680m underground in Ordovician Limestone overlain by numerous impermeable shale and dolostone units more than 200m thick. Additionally, Canada's Nuclear Waste Management Organisation (NWMO) is currently carrying out preliminary borehole drilling in volunteered siting areas (four in crystalline rock and one in sedimentary rock) to evaluate the possibility of locating a deep repository for spent nuclear fuel. The **US** currently has the world's only operating deep geological repository (WIPP – Waste Isolation Pilot Plant) which has stored radioactive waste generated through military activity in Permian salt formations 660m underground since 1999. Plans in the US for a repository for high-level wastes from commercial nuclear power generation deep in unsaturated volcanic rocks at Yucca Mountain in Nevada have been shelved since 2010 and a policy review is underway.

Asia

Since 2000, it has been **Japanese** national policy to dispose of all HLW in a geological repository. The country has been undergoing site selection to determine the suitability of its regions for hosting a geological disposal facility since 2015. As part of the site selection process Japan's Ministry of Economy, Trade and Industry has produced a nationwide map of geological suitability which aims to raise public awareness of all the districts that may be suited to hosting such a facility (Figure 7). In the **Republic of Korea** the government has committed to selecting a site for a GDF by 2028, with long-term storage in place for the existing and future inventory – which is significant due to the number of operational and planned nuclear power stations in the nation.

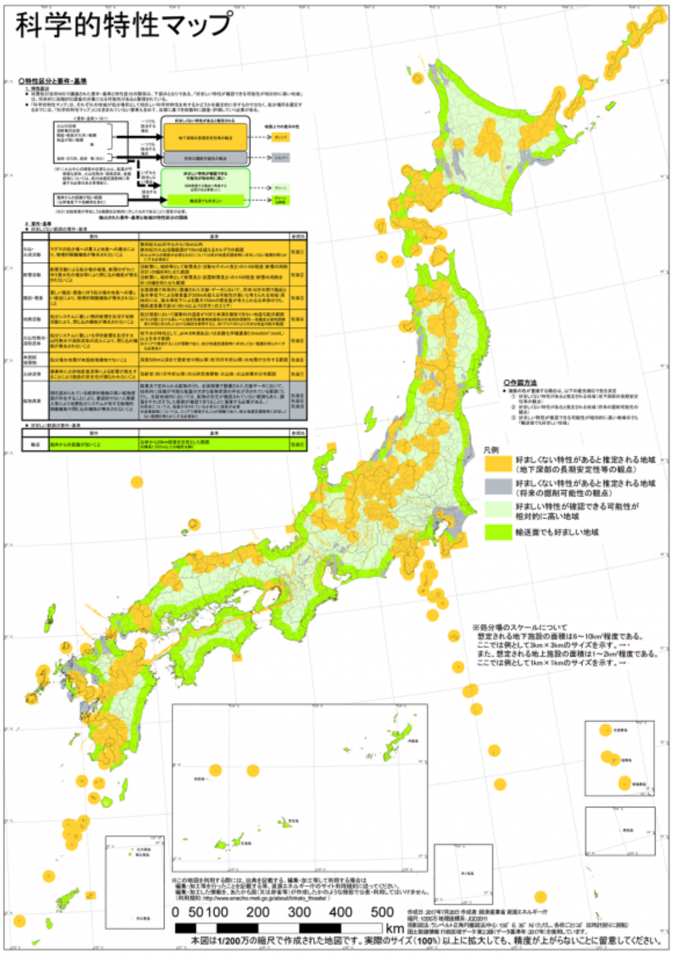

Figure 7 - A map showing the radioactive waste disposal potential of Japan. Areas shaded orange and grey are considered unsuitable for a repository. Pale green areas are considered potentially suitable, while dark green coastal areas are preferable.

Source: Japan METI.

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Geological knowledge, skills and expertise

The skills and expertise of geologists will be critical to the success of any Geological Disposal Facility.

Geology is key to the containment of radioactive waste underground by acting as one of the multiple barriers preventing its path to the surface.

Gathering, analysis and interpretation of geological data will be important as more detailed site assessments are required throughout the siting process.

Knowledge and experience of the subsurface will factor heavily into the design and construction of a disposal facility.

Regulation of the disposal of radioactive waste

The siting, design, construction and operation of a GDF will be regulated by the relevant environmental authority (Environment Agency or Natural Resources Wales), and also by the Office of Nuclear Regulation (ONR) which has regulated the UK's nuclear industry since 2005. The construction, design, operations and closure of any disposal facility in the UK will be subject to the Nuclear Installations Act (1965). The ONR have no say in the location of a GDF - this must be determined by community willingness, geological suitability and the professional judgement of RWM - however they can offer advice to Government, RWM, stakeholders or local authorities regarding the safety, security, nuclear safeguards and transport of radioactive materials.

See 'Regulating geological disposal: an overview' by the Office for Nuclear Regulation and the Environment Agency for more information on the regulation of radioactive waste disposal.

The Geological Society continues to respond to Government consultations on this topic and past responses can be viewed at www.geolsoc.org.uk/radioactivewaste.

In 2016, the Society assisted in convening an Independent Review Panel to review the National Screening Guidance developed by RWM Ltd., in direct response to the 2014 White Paper 'Implementing Geological Disposal'.

To find out more visit www.geolsoc.org.uk/policy.

About the Geological Society of London

The Geological Society of London is the UK national society for geoscience, providing support to over 12,000 members in the UK and overseas. Founded in 1807, we are the oldest geological society in the world. We provide professional support to our members, as well as impartial scientific information and evidence to policy makers and the public.

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As the national forum for the debate and development of cutting-edge Earth science, the Geological Society has a special responsibility to communicate this science and its importance to society, the Government, the media, other scientific communities and the general public.

Our Policy Team engages with Parliament, Government, industry and academia to fulfil this purpose. You can contact us at policy@geolsoc.org.uk.

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