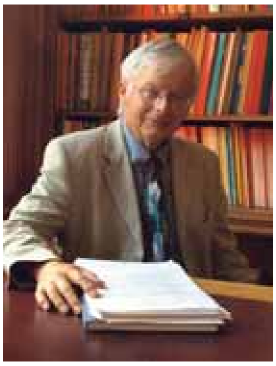
GEOLOGICAL DISPOSAL OF RADIOACTIVE WASTE



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Disposing of the radioactive waste products from nuclear sites is one of the most difficult challenges for society in the 21st century. Internationally, it is now accepted that burying radioactive waste deep underground in a Geological Disposal Facility (GDF) is the safest way to achieve this. There are guidelines drawn up by the IAEA, and several countries already have advanced plans. In the UK, a range of alternatives were evaluated by the independent expert Committee on Radioactive Waste Management (CoRWM) whose 2006 report favoured geological disposal.

In a GDF, the waste is contained within engineered barriers but the surrounding rocks provide an essential further barrier to prevent radioactive materials (radionuclides) escaping to the surface. The site must have suitable geology to fulfil this role. Past UK governments have been criticised for placing insufficient emphasis on geology, so I was delighted to be appointed as Chief Geologist to a new NDA company, Radioactive Waste Management Limited, responsible for planning a GDF. In July DECC published a White Paper: "Implementing Geological Disposal", which provides the policy framework.

Radioactive waste comes from various sources, including electricity generation and medical applications, and is in a variety of solid forms which place different constraints on disposal. The White Paper identifies a total of 650000m^3 of waste for geological disposal; this includes existing wastes, spent fuel (SF), uranium and plutonium and materials from planned new build. SF and High Level Waste (HLW) will account for over 99% of the radioactivity at the anticipated opening of the GDF in 2040, but will occupy less than 15% of the packaged volume. The most radioactive isotopes decay very rapidly, as illustrated in Figure 1: our existing HLW will have lost 97% of its activity by 2200. Remaining uranium and Intermediate Level Waste (ILW) make up the great bulk of the packaged volume. Being less active, they remain radioactive for longer; after one hundred thousand years, the repository will have radioactivity comparable to a natural uranium orebody.

The objective of geological disposal is to separate effectively radioactive materials from the surface. The rocks that host a GDF must provide a stable environment for construction of tunnels and vaults, and also not contain potential future mineral resources. The rock must restrict or prevent the flow of groundwater through the GDF once it has been sealed, minimizing the risk that radionuclides could be taken up into solution and transported to the surface. Understanding groundwater at a site is vital.

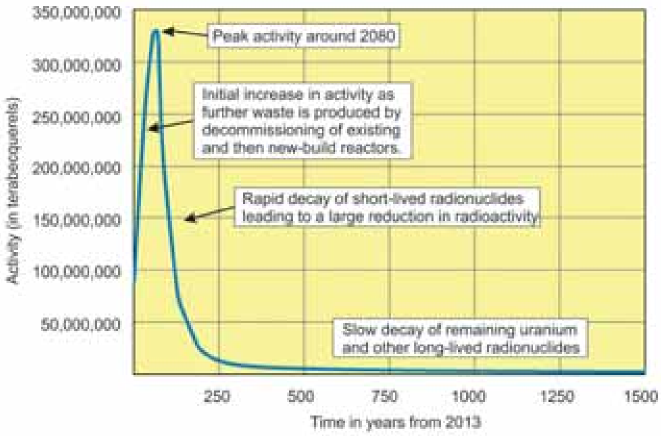

Figure 1: The decline in activity of the UK's total derived inventory of radioactive materials through time, from the date of the latest compilation (2013). This includes spent fuel from existing and planned new-build reactors.

Fluids such as water, brine, oil and gas occur in rocks in two distinct ways: they may occupy pores spread throughout the rock, or they may occur in cracks. Many sedimentary rocks are porous. In some, such as sandstone (Figure 2), pores are commonly well-connected and fluid moves through them easily making the rock permeable. In others, such as clays, pores are extremely small and fluids cannot move between them. These rocks are impermeable even if they have high porosity.

Crystalline igneous and metamorphic rocks have very low porosity but can hold water in spaced cracks (Figure 3). Permeability values measured in the field are always higher than those measured on small laboratory specimens without the cracks. The permeability of fractured rocks depends very much on how open fractures are at depth and how well they interconnect. Having cracks does not ensure high permeability.

Despite the importance of permeability for groundwater flow, the wider geological context also matters. Even if rocks are permeable, water only flows if there is a driving force. In the UK it is unusual for fresh, potable groundwater to extend more than a few hundred metres below the surface. Deeper rocks generally contain dense saline water which does not mix with overlying fresh water and is probably very old (>10000 years) (Figure 4). Irrespective of rock types, the presence of old, dense, stagnant groundwater at depth is a sign that radionuclides from a GDF will not be readily transported back to the surface, even over geological timescales, whereas if the groundwater is potable and young, there will be concerns that this could happen.

Internationally, three types of geological setting have been proposed as hosts for a GDF. Much early effort went into designing repositories in salt deposits. This is because salt provides an effective radiation shield, is impermeable to water and slowly flows underground, so that the cavities created to build the repository will naturally infill. The facility in New Mexico is hosted in salt. Other countries, including France and Switzerland, are planning to build their GDFs in clay or mudrock. Clays are impermeable and so provide a very effective natural barrier to the migration of radionuclides. Furthermore clays absorb many types of radionuclide from solution and so further retard their spread. Like salt, clays are weak and will flow, thus self-sealing cavities. Sweden and Finland are constructing repositories in strong granitic rocks with low permeability. The rock provides strength and facilitates construction and operation, while clay packing can be used to further isolate canisters of HLW or SF. The possibility of groundwater flow along fractures requires careful site selection but deep groundwaters in strong rocks are often distinct from shallow ones (Figure 4). Another option for a GDF constructed in strong rocks is a site where the GDF host rock is overlain by impermeable rocks such as clays.

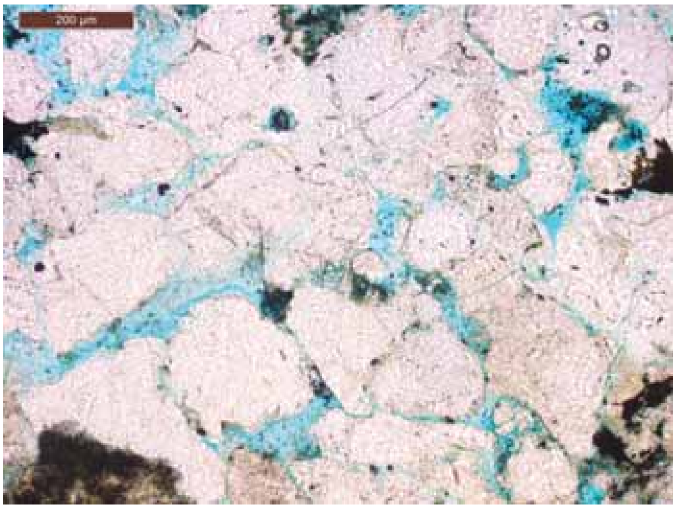

Figure 2: Photomicrograph of a typical reservoir sandstone that has been impregnated with a coloured resin so that the pore space, where water will reside below the water table, appears blue, and sand grains are mostly colourless. The field of view is about 1mm across.

Figure 3: Outcrop of hard, impermeable crystalline rock cut by discrete cracks that will permit water to move through them at depth.

Over the next few years, RWM will be screening the geology of England, Wales and Northern Ireland and, after public engagement and independent oversight, will publish the available information about geological properties that influence the suitability of rocks to host a GDF. What these precise properties are will be a matter for much discussion over the coming months, and only then will regional geology be evaluated. With geological guidance in place, communities throughout the UK will be invited to consider hosting a GDF, provided their geological setting offers good prospects.

For simplicity, unsaturated rocks close to the surface are not shown. On the left, fractures in crystalline basement rock retain stagnant saline waters at depth (dark blue) but have been flushed by fresh water (light blue) at shallower levels. They are overlain by a range of sedimentary rock types. While the coarser sediments contain freshwater in their pores, the clays retain old saline pore waters except near their margins. A similar range of rocks is shown on the right, but in a different sequence and no basement is present. Again, deep rocks retain old pore waters.

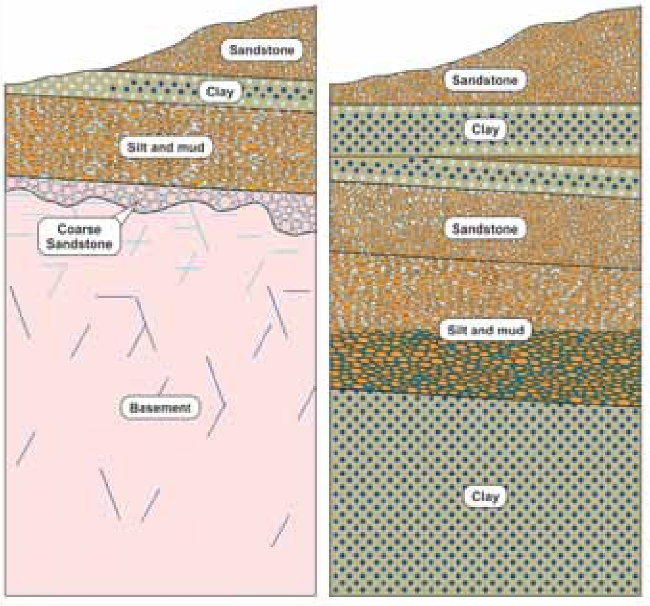

Figure 4: Examples of how groundwaters might be distributed through saturated rocks at depth in two idealised geological settings, represented by schematic geological cross sections. For simplicity, unsaturated rocks close to the surface are not shown. On the left, fractures in crystalline basement rock retain stagnant saline waters at depth (dark blue) but have been flushed by fresh water (light blue) at shallower levels. They are overlain by a range of sedimentary rock types. While the coarser sediments contain freshwater in their pores, the clays retain old saline pore waters except near their margins. A similar range of rocks is shown on the right, but in a different sequence and no basement is present. Again, deep rocks retain old pore waters.