ACHIEVING PERMANENT DISPOSAL OF HIGHER LEVEL RADIOACTIVE WASTES

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"You don't build a house without a toilet."[2]

"The tragedy of nations is perhaps this: that even the best rulers use up a piece of their people's future."[3]

Summary

Any country which has pursued a programme of nuclear power generation, or is considering doing so, must inevitably face the issue of disposing of the spent fuel and radioactive wastes from these activities. Such waste will, in many cases, present a radiological and potentially toxicological hazard over many thousands of years, timescales which are barely conceivable in terms of human history.

This paper looks at the issues around the topic and considers progress by reference to geological disposal projects in Finland and France. It reviews the failure of siting policy in the US, and the current state of play in the UK, considering the technical, legal, social and political issues.

What is clear is that very significant funding, time and expertise will need to be invested in the process of finding solutions for permanent disposal solutions for spent fuel and higher activity wastes if a global expansion of nuclear energy is to occur. In those countries where the process has been or is being successful, it can be observed what level of scientific, financial and social collaboration will be needed. In other countries such as the US and UK, history teaches what a fraught and uncertain process it can be. However, the risks for present and future generations of creating high level waste which will sit in surface or near surface stores indefinitely should not be regarded as tolerable.

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[1] The Committee (CoRWM) is an expert independent Committee appointed by the Secretary of State to advise the UK Government and Devolved Administrations on the management of radioactive waste. The views in this paper are personal and should not be taken as representing the view of CoRWM. I am most grateful to Sir Nigel Thrift (Chair of CoRWM) and Mark Kirkbride (fellow-member of CoRWM and chair of Sub-Group 2 on site evaluation) for their review and helpful comments on an earlier version of this paper.

[2] Jitsuro Terashima, President of the Japan Research Institute think tank and member of an expert panel advising the national government on energy policy after the Fukushima disaster. https://www.reuters.com/article/business/insight-japan-s-nuclear-crisis-goes-much-further-than-fukushima-idUSL4E8DQ0FP/

[3] Rainer Maria Rilke, *Early Journals*.

Introduction

Any country which has pursued a programme of nuclear power generation, or is considering doing so, must inevitably face the issue of disposing of the spent fuel and radioactive wastes from these activities. Such waste will, in many cases, present a radiological and potentially toxicological hazard over many thousands of years, timescales which are barely conceivable in terms of human history.

As a result, any disposal facility must be designed to contain the relevant radionuclides and isolate them from the biosphere; it must retard their dispersion and provide isolation from aggressive phenomena over the necessary timescales, by a combination of the waste packaging, engineered barriers and surrounding geology.[4] In the case of the most challenging wastes, which will pose a significant hazard over very long periods of time, this means that the only viable solution is deep geological disposal in a facility located underground within a stable geological formation.[5]

Practical experience of such facilities has been very limited, but this is now advancing as some states progress towards construction and operation of such facilities, and feasibility studies, underground research facilities, site specific safety cases and operational experience have strengthened confidence in the safety of geological disposal.[6] Whether to pursue the option of geological disposal remains a decision for individual states, taking account of national policy, the national waste inventory, and economic and social factors. Needless to say, the development of such facilities, to provide passive safety over millennia, comes at a high cost[7] and will of necessity take place over many decades.

The key problem in developing geological disposal facilities is not fundamentally a technical one, challenging though this is. Provided suitable host rock strata exists, underground tunnelling and mining technology can allow a geological disposal facility to be safely constructed and the waste packages emplaced. The Site Specific Safety Case will need to demonstrate the appropriate degree of isolation of the waste over the timescales necessary to ensure sufficient radioactive decay. Rather, the issue is one of siting and the political and community opposition which can arise from a proposal in a

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[4] IAEA Safety Standards, *Disposal of Radioactive Waste*, Specific Safety Requirements No. SSR-5, Vienna 2011, para. 3.32.

[5] IAEA Safety Standards, *Geological Disposal Facilities for Radioactive Waste*, Specific Safety Guide No. SSG-14, Vienna 2011, para. 1.2.

[6] Ibid. para. 1.5. See further IAEA Nuclear Energy Series No. NW-T-1.27, Design Principles and Approaches for Radioactive Waste Repositories, Vienna 2020, covering the full range of repository types.

[7] The estimated cost of Olkiluoto in Finland, discussed below, is around €818 million.

given area of population. This makes the siting process extremely sensitive and potentially unpredictable, even if geological disposal is supported by robust national policy. This may also be exacerbated by the fact that siting is a staged process which occurs over a protracted period of time, as areas of search are identified, potential sites are screened, and the site-specific information to support a safety case and the ultimate siting decision are gathered.

Siting involves not only consideration of geological information,[8] but also social, human and environmental factors and the potential effects on these, for example transportation of the waste to the facility, the disposal of large quantities of excavated spoil and the population fluctuations and demands on local services during the construction phase. These aspects have caused proposals to misstep and fail, perhaps notably in the US.

In the UK, these challenges have been recognised through a policy of voluntarism, such that a facility should only proceed with the agreement of the relevant "community", though this is not proving a straightforward proposition to implement.

The approach of top down decision making, where radioactive waste facilities are imposed on unwilling communities, sometimes referred to as "decide and defend", has been tried in the 1980s and 1990s and has largely been discredited.[9] The NEA's preferred approach is one of partnership if a licensable disposal facility is to be achieved, the key components being voluntarism, collaboration with local stakeholders, the agreement of community benefits packages, and some form of possible veto (whether formal or informal) by the local community.[10] Finland and Sweden are exemplified by NEA as proponents of this approach.

Imperatives to provide geological disposal facilities

In general, radioactive waste awaiting transportation to a geological disposal facility will be in an immobilised form, either within dry casks, or in some cases, within drums following a vitrification process, in which radioactive waste is blended with glass precursor materials and heated to above 1,000 degrees C to melt the components.

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[8] Including geology, hydrogeology, geomechanics, geochemistry & seismicity.

[9] Andrew Blowers and Göran Sundqvist, *Radioactive Waste Management – Technocratic Dominance in an Age of Participation*. Journal of Integrative Environmental Sciences, 7:3, 149-155 (2010).

[10] NEA*, Partnering for Long-Term Management of Radioactive Waste: Evolution and Current Practice in Thirteen Countries*. NEA No. 6823, OECD, Paris (2010).

Storage may be at the nuclear reactor site, or at a centralised facility. This storage can be via dry casks suitable for interim storage on site, or a more robust shielded container suitable for transportation which meets IAEA Safety Standards.[11] The storage systems may be above ground or excavated to below ground level (e.g. near surface vaults). The quantity of dry storage casks in use is indicated by the market in the Americas, where demand is highest, which was estimated at $1 billion in 2020.[12]

Delays in the provision of geological disposal facilities mean that the intended lifetimes of interim storage facilities will, in some cases, need to be extended. Conventional stores (as currently used) will usually require replacement and repackaging at not more than 200-year intervals.

It is debatable how acceptable the prolongation of interim storage can be . As an article in *Chemical & Engineering News* in 2020 pointed out,[13] more than 250,000 metric tonnes of highly radioactive wastes are in storage adjacent to nuclear power stations and weapons production facilities worldwide, with over 90,000 metric tonnes within the USA alone.

Much of this radioactive waste is now decades old, with a legacy going back to the 1940s, such that age is taking its toll on the containment, noting that these wastes will remain dangerous for many thousands of years. It also points out that even the well-established process of vitrification has uncertainties about how the steel canister protecting the glass may corrode, and what effect water ingress could have on the glass in terms of possible ion exchange and leaching of radioactive materials. This may include issues arising in damp repository conditions, particularly if cracks in steel canisters allow water into the microscopic gap between the waste and steel, triggering potentially unexpected reactions in the confined space.

Even for the more easily dealt with solid spent fuel assemblies, stress fractures may occur at weld seams, leading to corrosion affecting the stainless steel used in dry casks. This may be further exacerbated by the coastal locations of many nuclear power plants, with exposure to sea-salt aerosol which would be highly likely to accelerate corrosion.

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[11] IAEA Safety Standards Series No. SSR-6 (Rev. 1) Regulations for the Safe Transport of radioactive Material (Vienna, 2018). In the UK for example a number of organisations have adopted the use of Robust Shielded (RS) packages for higher activity waste, which are thick-walled, ductile cast iron containers weighing up to 35 tonnes. Work is under way to develop a transport version of this package meeting IAEA standards.

[12] https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste

[13] C&EN Vol. 98, Issue 12, March 30, 2020. https://cen.acs.org/environment/pollution/nuclear-waste-pilesscientists-seek-best/98/i12

Facilities currently storing radioactive waste will predominantly have been sited and designed in an era predating the recognition of the potential effects and risks posed by climate change, such as sea level rise, coastal erosion and extreme weather events. These may all impact on the safety of prolonged interim storage facilities.

Statistically, the earth is due for another extreme solar storm during this century which could inflict long term power outages that could compromise the safety of stored spent fuel.[14]

There are also concerns being voiced about the potential risks presented by terrorism and armed conflict or war. The nature of the packaging or vitrification of radioactive waste most likely indicates that in practice it would be difficult for these materials to be dispersed as a result of a terrorist attack, such as to threaten harm to life, but the necessary clean-up would be both extremely difficult and expensive. Vulnerability to certain types of missile strike may be different, as shown in a recent wargame designed by the Washington-based Nonproliferation Policy Education Center (NPEC) reported in June 2023 in the Bulletin of the Atomic Scientists.[15] Spent fuel contains accumulated highly radioactive fission products, including iodine, caesium and strontium, which would result in a radiological emergency if released. Clearly, any such attack would be contrary to norms of international behaviour (though not explicit international law), however they have occurred in the past and may well do so again in future.[16]

Moreover, studies of history clearly demonstrate that political economies operate in cycles, with almost inevitable upheavals and societal breakdown occurring regularly; indeed Western societies such as the USA are moving, or have moved, into socio-economic conditions conducive to such disruption.[17]

All of these factors strengthen the imperative for swift action to be taken for the development of geological disposal facilities to move spent nuclear fuel and higher-level radioactive waste deep from surface storage into underground vaults, so that it is out of harm's way.

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[14] https://thebulletin.org/2024/04/spent-nuclear-fuel-mismanagement-poses-a-major-threat-to-the-united-states-heres-how/

[15] https://thebulletin.org/2023/06/wargame-shows-attacks-on-reactors-would-cause-meltdowns-and-military-paralysis/#post-heading

[16] https://www.polytechnique-insights.com/en/columns/geopolitics/how-to-protect-nuclear-power-plants-in-wartime/ ; https://www.project-syndicate.org/onpoint/ukraine-shows-nuclear-reactors-at-risk-during-war-by-bennett-ramberg-2022-08

[17] See Peter Turchin, *End Times: Elites, Counter-Elites and the Path of Political Disintegration*. Penguin Random House, UK, 2023.

Progress

The World Nuclear Association website includes a helpful table showing the progress of various countries in relation to deep geological repository projects.[18] The site at Onkalo, Finland (discussed below) has a commissioning date of 2024.

Next in line is the Cigéo facility in France, where a construction licence was submitted in 2023, and Forsmark in Sweden where the application for a construction licence was approved in 2022. Both have proposed commissioning dates in the first half of the 2030s.

A site has been selected in Switzerland, at Nördlich Lägern, where general licence applications are due to be submitted to the Federal government in 2024, with approval anticipated around 2030, subject to an optional referendum, and with 2060 as a proposed commissioning date. Other countries are still at the selection stage for varying areas of search; these include Canada, China, Czech Republic, Germany, Hungary, India, Japan, Slovakia, and the UK. In the USA the process has stalled, as discussed below.

Olkiluoto

In 2020, the Director General of the IAEA described the world's first deep geological facility at Olkiluoto, off the south-west coast of Finland, as "game changer".[19] The commitment and drive of the Finnish government, and the companies involved in developing the project, are clearly an example to other countries. It can be seen in the context of a country deeply committed to nuclear power as part of its energy strategy.

It is worth recalling some of the history of the project. The Nuclear Energy Act in Finland was amended in 1994 to provide that nuclear waste arising in Finland should be disposed of within Finland. From 1983 until 2000 a screening exercise was undertaken which covered the whole Finnish territory. This resulted in four sites being identified for further investigation, one of which was Olkiluoto, which has hard rock (granite) geology. The levels of public support were assessed, and two sites, Olkiluoto and Hästholmen, were found to have the highest levels of support. Of these

[18] https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste
[19] https://www.iaea.org/newscenter/news/finlands-spent-fuel-repository-a-game-changer-for-the-nuclear-industry-director-general-grossi-says

sites, Olkiluoto had the more favourable geology, and was therefore proposed to the Finnish government as the preferred site. Approval was confirmed by the municipality where the site is located, Eurajoki, and the decision was ratified by the national government in 2001. Excavation began in 2004 and a licence to construct the final disposal facility was issued in 2015. Prior to issuing the licence to construct the repository, there were extensive underground investigations to study the characteristics of the rock. The facility, known as Onkalo, was developed by Posiva, a company owned by the two companies responsible for producing nuclear energy in Finland, Fortum Oyj and TVO (Teollisuuden Voima Oyj). The GDF is expected to receive canisters of fuel for around 100 years.

The disposal concept, known as KBS-3, shared with the proposed Swedish facility at Forsmark, utilises copper canisters for waste containment; copper is known to have a long-term resistance to corrosion from the findings of ancient copper tools and geological copper deposits.

It is interesting to consider why the process in Finland progressed in a relatively smooth manner. Perhaps a starting point lies in the origins of the Finnish nuclear power programme in the 1970s; the Three Mile Island accident in the US in 1979 focused minds on nuclear risks, and the export of waste to the then Soviet Union was seen as potentially storing up trouble for the future. Accordingly, in 1983 the Finnish Parliament required the two nuclear power companies, Fortum and TVO, to set aside funds and begin the process of planning for a disposal facility. This created a very significant State Nuclear Waste Management Fund, mandated by the Nuclear Energy Act of 1987 and overseen by its Ministry of Economic Affairs and employment. Accordingly, Posiva has for many years been well resourced in undertaking the necessary research. It has also been supported and overseen by the Finnish Research Programme on Nuclear Waste Management (KYT), an independent body charged with assimilating Finland's overall nuclear waste management base from across a number of different organisations, including the regulatory authority STUK, the Geological Survey of Finland (GTK) and various specialist consultancies.

It is also worth noting that the preparation of the long term safety case was a wide ranging and very demanding exercise, as it was necessary to maintain public trust and confidence, which as well as including rigorous science, incorporated some imaginative and eclectic processes in seeking to look tens and hundreds of millennia ahead to the point when risks from the waste would be at their greatest, after the inevitable failure of the primary containment.[20]

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[20] The projections include final waste canisters being deposited in 2120 and tunnels backfilled, 22,000 years as the earliest projection for Finland's next Ice Age, 26,122 years when Plutonium-239 reaches its half-life, and 2.3 million years when Caesium-135 reaches its half-life. https://spectrum.ieee.org/finlands-nuclear-waste-solution

One aspect of siting was identifying a location of little interest in terms of metal deposits and non-saline, usable groundwater. Plainly, the process did ultimately prove successful in engendering and maintaining trust, whilst also bucking the trend of "deflation of expertise" which is so prevalent in contemporary Western society, defined by Ialenti in his excellent book on the Finnish programme, *Deep Time Reckoning*, as:[21]

> *"… what happens when political power is commonly gained through populist mockery of expert authority, experts' voices are too often drowned out by the noisy clamors of knee-jerk tweets and self-published blogs, and adepts' inquisitive spirits are frequently dulled by new corporate-managerial reforms and constrained by bureaucratic protocols."*

It is therefore possible to perceive in Finland a high and sustained degree of national commitment to finding a solution to the problem of spent nuclear fuel and radioactive waste. Public trust in the Finnish Radiation and Safety Authority (STUK) is very high, and the safety issue was essentially depoliticized at a local level.[22] There has also been a move or evolution from technocratic management towards a more participative and communicative approach.[23] This methodology has been shared, albeit with some differences, with Sweden.

Both countries have in common a society which is consensus-driven and with high levels of trust. Whereas the Swedish approach has been characterised as "involved partnership" which allows for challenge, and even modification of the policies and actions of the operator and authorities, the approach in Finland is more that of a "bystander partnership" which is characterised by trust in the safety authorities, and with the primary issue of concern being community socio-economics. In both countries the host municipalities have chosen not to exercise their right of veto and are supportive of the siting of the repository in their area.

The process in Finland has been a long and sustained one. There were important milestones in the 1990s in the Eurajoki municipality, including a 1997 study on the economic competitiveness of the

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[21] Vincent Ialenti, *Deep Time Reckoning: How Future Thinking Can Help Earth Now*, 2020, Massachusetts Institute of Technology.

[22] Tuuli Vilhunen, Matti Kojo, Tapio Litmanen & Behnam Taebi *Perceptions of justice influencing community acceptance of spent nuclear fuel disposal. A case study in two Finnish nuclear communities* , Journal of Risk Research, 25:8, 1023-1046 (2022). https://www.tandfonline.com/doi/pdf/10.1080/13669877.2019.1569094

[23] Mika Kari, Matti Kojo and Markku Lehtonen, *Role of the Host Communities in Final Disposal of Spent Nuclear Fuel in Finland and Sweden*. Progress In Nuclear Energy Volume 133, March 2021, 103632. https://www.sciencedirect.com/science/article/pii/S0149197021000044

municipality and a 1998 analysis known as the "Olkiluoto vision", which included a spent nuclear fuel repository.[24]

The USA

If Finland can be considered to be an exemplar of a successful siting process, then the USA can only be seen as the reverse. The history to date could possibly be described as one of "anti-voluntarism" whereby the process has been subverted and stalled by local interests and political power play.

The US does already have a deep geological facility, the first in the world before Olkiluoto, the Waste Isolation Pilot Plant (WIPP) near Carlsbad in New Mexico. This was developed to take defence-related transuranic[25] waste, for example laboratory and industrial waste contaminated with transuranic radionuclides. Although much less dangerous than spent fuel and high level waste, such waste remains radioactive for thousands of years. At WIPP there is no reliance on waste packaging for isolation, with this being provided by the surrounding salt formations which are ~2,000 feet thick. Site characterization began in the mid-1970s, excavation commenced in the 1980s and the site began to receive radioactive waste in 1999 from defence related locations around the US. The site was selected by the US Department of Energy (the DOE, formerly the US Atomic Energy Commission) on the basis of positive interest from the local New Mexico community, and because a site previously under consideration in Kansas was facing local opposition and featured previously undiscovered oil and gas resources.

The key technique used to achieve public trust at WIPP was the New Mexico Environmental Evaluation Group (EEG), created in 1978 as an independent body charged with overseeing the project and verifying statements and studies undertaken by the DOE. It seems likely that the project would not have progressed were it not for the work of EEG, for example by investigating and instigating studies when brine deposits under pressure were found beneath the site. The US Congress authorised construction in 1979, but further approval was necessary from Congress before the facility could be used. This led to a political battle and to legislation which included provision for revised safety standards to be approved by the Environmental Protection Agency.

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[24] NEA: *Stepwise Decision Making in Finland for the Disposal of Spent Nuclear Fuel*. OECD, 2002, p. 84
https://www.tandfonline.com/doi/pdf/10.1080/13669877.2019.1569094

[25] The transuranium elements (also known as transuranic elements) are the chemical elements with atomic numbers greater than 92, which is the atomic number of uranium. All of them are radioactively unstable and decay into other elements. With the exception of neptunium and plutonium which have been found in trace amounts in nature, none occur naturally on Earth and they are synthetic.

The WIPP site has been controversial for various reasons. Two significant accidents in 2014 (a truck fire and radioactive release from breach of a container) called its safety credentials into question and led to reduced operations.[26] According to the US Government Accountability Office, it remains unclear whether the root causes of the accidents have been addressed.[27] Further, WIPP has remained the only facility of its kind for transuranic wastes, despite the understanding being at the time of construction that the burden would be shared by other sites. This has led to pressure on space and proposals for extension in time and physical extent, creating tensions with the state of New Mexico.[28]

The facility does however have very strong, though not universal, support within the local community and indeed is a source of pride, as well as jobs and economic support: it has been reported that the first trucks carrying waste containers to the facility were jeered at while passing through Santa Fe, but cheered on arrival in Carlsbad.[29]

A facility for receiving spent fuel and high-level radioactive waste, both being much more hazardous than that authorised for disposal in WIPP, is a very different proposition, and so it has proved with the stymied proposal for a high-level waste repository at Yucca Mountain, Nevada. The initial phases of the saga have been set out in various publications.[30]

The US arrangements for siting sit firmly within a legislative context. The problem of permanent disposal of high-level radioactive waste has been growing ever since the inception of the Manhattan Project in the early 1940s, but was not addressed in law until the Nuclear Waste Policy Act of 1982 (NWPA), when attention was drawn to the huge disparity of funding for developing the military and peaceful uses of nuclear power and that devoting to looking for solutions to the wastes being generated. At the time of the passage of the NWPA, much effort was expended by the legislators in seeking to preclude consideration of their own constituencies as host sites for a repository.

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[26] David M. Klaus, *What really Went Wrong at WIPP: An insider's view of two accidents at the only US underground nuclear waste repository* (2019). https://doi.org/10.1080/00963402.2019.1628516

[27] https://www.gao.gov/products/gao-22-105057.

[28] See https://sourcenm.com/2022/08/08/nms-nuclear-waste-site-could-be-open-forever-despite-2024-closure-date-advocate-warns/

[29] https://fortune.com/2023/05/02/nuclear-waste-storage-new-mexico-carlsbad-wipp/.

[30] A thorough account up to 2007 is given in Robert Vandenbosch and Suzanne E. Vandenbosch, *Nuclear Waste Stalemate* (2007) University of Utah Press.

Scientific and technical considerations could already be seen to be dominated by politics. The most debated provision of the NWPA was that allowing a selected state to veto its selection for a site, but with the ability for that veto to be overridden by a majority vote in both houses of Congress.[31] The process has been described as searching for a "technically appropriate subsurface with a politically compliant governor on top".[32] The exigent timescales required by the NWPA for progressing a site were somewhat antithetical to an open consultative process and were likely to contribute to "insufficient attention to local concerns and participatory opportunities or result in inappropriate compromises".[33]

There followed preliminary studies by the DOE at several prospective sites, which generated local protest at various sites, particularly those in the Eastern states. The choice was narrowed down to three candidate sites in the West, and in 1987 the Nuclear Waste Policy Amendments Act established Yucca Mountain as the only site to be investigated further: the Amendments Act also suspended the requirement in the NWPA for an Eastern site to be pursued in tandem.[34]

Nevada at that time had the least political influence of the three Western states with candidate sites,[35] and the Amendments Act was notoriously referred to as "the Screw Nevada bill".[36] The passage of the Amendments Act also illustrated the significance of dominant political actors, in that case Senator J. Bennett Johnston (D-LA), Chair of the Senate Energy and Natural Resources Committee., who was well-informed, politically astute and had an impressive grasp of scientific and

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[31] Ibid. p. 2.

[32] Ibid. p. 53.

[33] Ibid. p. 56.

[34] The Act also directed DOE (without ay technical justification) to terminate research programmes on crystalline rock (effectively granite) which was the only likely medium for a repository in Northeastern and Midwestern states: ibid. pp. 41-42, 84. As has been pointed out, the somewhat modest title of the Act belied the massive changes in nuclear waste policy which it introduced. Ibid. p. 71.

[35] The other two sites were Hanford in Washington State, and Deaf County in Texas. Hanford, as well as being located on potentially problematic basalt, has a very unhappy history of nuclear waste management from the US defence programme. Deaf County was in a very productive and prosperous agricultural area, with some of the best land in Texas, and was on a salt formation. At that time there was concern about the safety of salt domes following the 1987 accident at the Gorleben site in Germany caused by the pressure of salt creep. Moreover, the Speaker of the House of Representatives was from Texas and the House majority leader was from Wahington State: Nevada was the smallest and politically weakest of the three states.

[36] Ibid. p. 3. It may also be noted that various proposals for centralised interim storage sites (monitored retrieval storage) for example in, Tennessee and Utah, failed because of local opposition: ibid. p. 8.

technical issues.[37] The lack of transparency in site selection was however striking: "*In the end, it was not the DOE, which had conducted extensive studies of the sites, that picked the site but, rather, a conference committee that operated behind closed doors*."[38] It could be argued that in taking the decision, Congress had placed the DOE in an untenable position of having to justify the site's suitability, rather than conducting a dispassionate analysis of its viability and whether it was the best site.

There followed a draft Environmental Impact Statement and a Science and Engineering Report by the DOE, and subsequently Presidential approval of the proposal for Yucca Mountain. Nevada then exercised its statutory veto, which was overridden by strong majorities in both houses of Congress in mid-July 2002 – a time of great national concern about vulnerability to terrorist attacks following 9/11. However, political developments intervened once again.

Opponents to Yucca Mountain found an effective champion in Senator Harry Reid (D-NV), who had a firm grasp of the legislative process and increasing political power. Underground test facilities were constructed at Yucca Mountain; work was also undertaken on projected performance by probabilistic modelling, which ran into legal difficulties when the DC Court of Appeals held that the EPA had unlawfully limited the period for assessing compliance with dose standards to 10,000 years, well before the likely peak dose (between 100,000 and 1 million years). Even within 10,000years there was arguably a failure to provide sufficient weight to the risk of volcanic activity, which while low in terms of probability would have significant consequences for exposure to radiation.

A significant part of the public opposition to Yucca Mountain within Nevada was based on mistrust of government: those affected by fallout from the test detonation of "Dirty Harry" in 1953 (a 32-kiloton bomb which produced the most fallout of any tested within the US mainland) did not receive any compensation until the 1990s.[39] International concerns also played into the same narrative: a replica spent fuel flask was transported around Nevada and other Western States in 2000 in the "Mobile Chernobyl" campaign to highlight the risks of mass transportation of spent fuel.

In 2006 the DOE proposed 2017 as the date the Yucca Mountain facility would begin waste acceptance. During the administration of President Obama, the project met its political nemesis in

[37] Ibid. p. 84.

[38] Ibid. p. 87.

[39] Ibid. p. 117.

the 2011 amendments to the Department of Defence and Full-Year Continuing Appropriations Act. It was, by then, seriously contested by the public and many politicians, as well as state and local administrations, and by Senator Harry Reid who had been the leader of the Senate since 2006. By 2008 the project's budget had been significantly curtailed and attempts to find a different and less politicised approach, through the so-called Blue Ribbon Commission on America's Nuclear Future, came to nothing, and under President Trump the DOE ceased deep borehole activities.

In May 2021 the Energy Secretary Jennifer Graham announced that Yucca Mountain would not feature in the President Biden administration's plans for nuclear waste disposal. Today the site has been abandoned and nothing exists but a boarded-up tunnel entrance.[40] The site, in technical terms, has undeniable merits: its desert location, distance from centres of population (Las Vaga is 90 miles away), closed hydrologic basin and surrounding Federal land. On the other hand, Nevada highlighted some problems – its location in an active seismic region, with earthquake induced faults, potential fracture pathways in the rock, and some evidence of hydrothermal activity within the repository block. But irrespective of the science, as the Blue Ribbon Commission reported to President Obama, experience suggests that "any attempt to force a top-down, federally mandated solution over the objections of a state or community" is likely to be expensive, time-consuming, and ultimately unsuccessful: "The construction of a permanent nuclear waste repository will require not only the backing of scientists and politicians but also the consent of a host community."[41] Yucca Mountain can be seen as a flawed process which failed.

Canada

Some brief comments may be made on the situation in Canada, where the Nuclear Waste Management Organisation (NWMO) is considering two community locations in Ontario for a deep GDF. One site is in the municipality of South Bruce, where the local council volunteered to be a host in 2012. Since then deep test drilling has begun and according to a 2021 report the community has received over $3.2 million in community funding, used for many different purposes quite unrelated to the proposed project, including salaries of municipal employees, funding doctors, upgrading abstraction wells, and purchasing fire-fighting equipment.[42] This has led to controversy as to

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[40] https://www.yuccamountain.org/faq.htm

[41] Dawn Stover, *The "scientisation" of Yucca Mountain*.
https://www.yuccamountain.org/pdf/dawn_stover_102011.pdf.

[42] https://www.cbc.ca/news/canada/london/nuclear-waste-disposal-site-teeswater-south-bruce-1.6013827.

whether NWMO is funding basic municipal expenses in a way which might make the municipality financially dependent and therefore making it harder to disentangle itself by saying no to the project.

France

The process of developing a repository in France is managed by ANDRA (*Agence nationale pour la gestion des déchets radioactifs*). Studies on possible locations date back to the 1960s and by the 1990s the focus was on clay and granite as potential formations. Legislation in 1991 (the Loi Bataille) required research at a number of sites, with ANDRA narrowing down the choice from four to three. In 2019 ANDRA filed with the Nuclear Safety Authority (ASN) a request to build the Cigéo Centre (Industriel de Stockage Géologique) at Bure in the Meuse Département, within Kimmeridgian claystone in the Paris Basin. The project has been the subject of some protest and resistance by anti-nuclear activists, who were evicted from the forest site of the proposed air vents in 2018.

ANDRA applied for a construction licence (DAC) in 2023, which ASN will consider over a period of several years, beginning with a 30-month technical examination phase, followed by consultation and a public inquiry, probably in 2026.[43] The Meuse and Haute-Marne departments are quite sparsely populated. The Loi Bataille emphasises public participation, and public debates have been held. There appears to be strong local support, with the main opposition being non-local; strikingly a 2020 poll showed that 65% of those polled within 15 km of the site trusted ANDRA to manage radioactive waste in the long term.[44] There is a strong imperative to make progress since the cooling pool facilities at the La Hague reprocessing facility in Normandy will reach their capacity by the end of the decade.[45]

The United Kingdom

The UK, perhaps unfortunately, has some special features when it comes to finding a solution to higher level radioactive wastes. The first stems from the devolved nature of government in the UK, with the Scottish Government and Welsh Government having devolved authority concerning waste disposal.

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[43] https://world-nuclear-news.org/Articles/Application-lodged-for-construction-of-French-repo.

[44] https://www.stimson.org/2021/visit-to-the-site-of-frances-future-high-level-waste-repository/.

[45] https://www.reuters.com/business/environment/france-seeks-strategy-nuclear-waste-site-risks-saturation-point-2023-02-03/.

There is a UK-wide policy framework for managing radioactive substances and nuclear decommissioning, recently updated in May 2024, to which the Scottish and Welsh Governments are parties.[46] Whilst it is the policy of the UK Government and the devolved administrations to manage the UK's most hazardous waste through geological disposal, the Scottish Government's policy is quite different and Scotland is not participating in the geological disposal programme.[47] This is despite the fact that spent fuel has been generated by Scotland's nuclear power stations and that exotic wastes have arisen from various experimental reactor facilities at the Dounreay site in Caithness.

Therefore, the search for a possible GDF site is proceeding in England and Wales only. Scotland has its own policy for the management of higher activity waste, which is that long-term management should be in near-surface facilities, located as close as possible to the site where the waste was produced. This policy was stated in 2007, shortly after CoRWM recommended geological disposal as the best available approach for the long term management of higher activity waste, and was said to be so that the waste could be monitorable and retrievable, and the need for transporting it over long distances is minimal.[48] The Scottish Government stated that "… *we do not accept that it is right to seek to bury nuclear waste, which will remain radioactive for thousands of years, in underground sites. This out of sight, out of mind policy should not extend to Scotland*".[49]

This of course effectively precludes Scotland from any possible GDF site, in circumstances where there are large areas of suitable geology in remote locations in Scotland.[50] Whilst the Welsh Government policy is for geological disposal and has its own policy framework on working with communities,[51] it is questionable whether a repository sited in Wales to take waste from other parts

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[46] https://assets.publishing.service.gov.uk/media/6632371769098ded31fca7c1/managing-radioactive-substances-and-nuclear-decommissioning-uk-policy-framework.pdf.

[47] Ibid. para. 8.56.

[48] https://www.gov.scot/publications/radioactive-waste-policy-statement/.

[49] Ibid.

[50] There were high risk materials such a plutonium and exotic spent fuels at Dounreay which have been transferred to Sellafield under the consolidation of spent fuel and nuclear material programme. Also some highly enriched uranium was transferred from Dounreay to the USA by air. It is proposed that spent fuel currently in storage at power stations in Scotland would in due course be transferred to a GDF, presumably in England. See https://www.gov.uk/government/case-studies/consolidation-of-spent-fuel-and-nuclear-materials.

[51] https://www.gov.wales/sites/default/files/publications/2019-04/geological-disposal-of-higher-activity-radioactive-waste-guidance-for-communities.pdf.

of the UK would be acceptable in political or community terms, though this has not been stated explicitly, and no proposed sites in Wales are currently under consideration. If that is correct, only about 75% of the UK mainland landmass is in fact available as an area for a GDF.

The second peculiar national factor is the nature of the UK's waste inventory. Dealing with spent fuel from nuclear power generation, whilst not easy, is markedly more straightforward than dealing with the radioactive wastes from the UK's long, and essentially unhappy, history of reprocessing at Sellafield.[52] That waste, either high-level and heat generating, or the worst forms of intermediate level waste, now represents a major financial and technical challenge for the UK, long after the profits from taking waste for reprocessing from overseas have ceased. Much of this inventory still remains untreated and unpackaged,[53] though progress is being made on reducing the worst risks.[54] It does not seem unreasonable to suggest that it may be easier to engage positively with the public in respect of spent fuel, which has plainly benefited the public from generating electricity (as in Finland) than the complex brew of spent fuel types and reprocessing residues the UK holds.

The current UK policy is one of voluntarism, though interestingly the word does not appear in the Waste Policy: it is referred to as "community consent-based processes".[55] The process for identifying a suitable site for a GDF in England is at Appendix 1 and in Wales (though as explained above the political reality, at least at the present time, is most likely that no site in Wales will come forward).

The task of engaging with potentially willing communities falls to Nuclear Waste Services (NWS), a subsidiary of the Nuclear Decommissioning Authority, the statutory body charged with dealing with and cleaning up nuclear sites and their radioactive and industrial waste. A number of features of the "working with communities" policy can be identified (largely taken verbatim from Appendix 1 of the Policy though here rearranged sequentially).

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[52] For an account, see Stephen Tromans, *Nuclear Law*, Hart Publishing (2010), pp. 14-17. For a highly critical account by an American outsider to the UK, see the Pulitzer Prize winning writer Marilynne Robinson, *Mother Country: Britain, the Welfare State and Nuclear Pollution*, Farrar, Straus & Giroux, New York (1989).

[53] See the report on the 2022 Waste Inventory. https://www.gov.uk/government/case-studies/consolidation-of-spent-fuel-and-nuclear-materials .

[54] https://www.gov.uk/government/publications/nuclear-decommissioning-authority-business-plan-2024-to-2027/nuclear-decommissioning-authority-business-plan-2024-to-2027

[55] https://assets.publishing.service.gov.uk/media/6632371769098ded31fca7c1/managing-radioactive-substances-and-nuclear-decommissioning-uk-policy-framework.pdf, para. 8.71.

(1) A successful consent-based process needs a willing community with relevant principal local authority support. The process itself must be open, transparent, as flexible as possible and democratically accountable.

(2) Discussions about a proposed location for a GDF can be initiated by anyone or any group of people with an interest in the siting process, and who wish to propose an area for consideration. Examples include local authorities, landowners, businesses, community groups or interested individuals. NWS may also proactively encourage interested parties and local communities to come forward and engage. It is possible that an interested party may suggest a location for a GDF beneath the UK's territorial waters, with the surface facilities being located on land, which could be a feasible option. Government owned land may also be put forward.

(3) Once NWS and the interested party have had an initial exchange of information and agree that the proposal merits further consideration, they must jointly inform all relevant principal local authorities and open up discussions more widely in the community. Increasingly detailed investigations will be carried out by NWS over a number of years.

(4) NWS, as the delivery body, will work in partnership with communities to provide answers to their questions, so the community can make an informed decision about whether to support a facility being developed in their area.

(5) In order to begin a conversation with the people in the area, the interested party, NWS, an independent chair and an independent facilitator will form a Working Group. All relevant principal local authorities that represent the people in all or part of the area under consideration must be invited to join the Working Group. This early part of the process is essentially about fact finding, gathering information about the community and providing information to the community about geological disposal.

(6) An early task for the Working Group is to identify a Search Area. The Search Area is the geographical area within which NWS seeks to identify potentially suitable sites to host a GDF. Defining the boundaries of the Search Area is important in order to identify appropriate membership for the Community Partnership, including relevant principal local authorities, and to determine eligibility for Community Investment Funding.

(7) As it identifies the Search Area, the Working Group will start work to understand the local area and any issues or questions the community within it might have. Funding will be provided for

independent support and a facilitator to support the Working Group. The independent facilitator will be a member of the Working Group and will help to bring together different views so that discussions progress in a constructive and informative manner.

(8) A Community Partnership can only be formed and continue to operate if one or more relevant principal local authorities in the Search Area agree to participate. There must be at least one relevant principal local authority representing each district or unitary authority electoral ward in the Search Area. In an area with two tiers of local government (i.e. district and county) in order to maintain flexibility, it is not a requirement that both join. All of the Search Area must be represented by a relevant principal local authority on the Community Partnership. If a relevant principal local authority decides to leave the Community Partnership with the result that part of the Search Area (or, once identified, the Potential Host Community) is no longer represented by any of the relevant principal local authorities on the Community Partnership, then it will no longer form part of the Search Area. The Community Partnership should seek to include representation from parish and town councils, though given the potentially large number of parish or town councils in any given area, it may not be feasible for them all to be members of the Community Partnership.

(9) The Community Partnership provides a vehicle for sharing relevant information and to find answers to the questions the community may have about geological disposal and its impacts, the siting process and how the community could benefit. The prospective members of the Community Partnership will develop and sign a Community Partnership Agreement. Once the Community Partnership Agreement is in place Community Investment Funding can be made available.

(10) The Community Partnership will need to engage with the community over a long period of time. Getting people actively involved on any issue can be challenging and it is possible that vocal minorities can dominate debate. It will therefore be important to open up community participation through a wide number of channels.

(11) Funding for engagement will be provided to Working Groups and Community Partnerships. The Community Partnership may also commission reports and research on specific topics from independent experts, as part of its agreed programme of activities. Given the range of advice and information available it may be that the Community Partnership receives conflicting statements from different parties. If that is the case the Government is making available a

mechanism through which the Community Partnership can access independent experts for views on contested and unresolved scientific or technical issues.

(12) A GDF should have a positive effect on the local economy in terms of job creation. It is also likely to involve major investments in local transport facilities and other infrastructure and create secondary benefits within industry, local education resources and local service industries. However, these benefits will not materialise for a number of years. The Government is therefore making available Community Investment Funding to those communities that form Community Partnerships and participate in the process. During the early parts of the siting process, the UK Government has committed to make available Community Investment Funding of up to £1 million annually per community. This will rise to up to £2.5 million annually per community where deep borehole investigations take place to assess the geological suitability of a site. The funding can be used to pay for projects, schemes or initiatives that:

(a) improve community well-being, for example improvements to community facilities, enhancement of the quality of life or health and well-being of the community;

(b) enhance the natural and built environment including cultural and natural heritage, especially where economic benefits, for example through tourism, can be demonstrated; or

(c) provide economic development opportunities, for example employment opportunities, job creation, skills development, education or training, promotion of local enterprise, long-term economic development or economic diversification.

The Community Investment Funding should be administered by a third party with legal personality in order to provide additional transparency and independence from NWS, as the conduit of the funding.

(13) The Government will provide additional investment to the community that is ultimately selected to host the GDF., will replace the Community Investment Funding. Investment could include improved local education and skills capacity, improved transport infrastructure or improved recreational facilities. This additional investment will be significant and comparable to other international GDF projects.

(14) To ensure democratic accountability, the relevant principal local authorities on the Community Partnership will take two key types of decisions. They will have the final say on:

(a) whether to seek to withdraw the community from the siting process (through invoking the Right of Withdrawal);

(b) if or when to seek the community's views on whether it wishes to host a GDF (i.e. proceed to a Test of Public Support).

Although the relevant principal local authorities will have the final say in relation to these two key decisions, they should involve other members of the Community Partnership in discussions on whether they intend to seek to withdraw the community from the process and the appropriate time to launch a Test of Public Support. All relevant principal local authorities on the Community Partnership must agree before the Right of Withdrawal can be invoked or the Test of Public Support can take place. For example, in an area with two tiers of local government and where both relevant principal local authorities are on the Community Partnership then they must both agree to invoke the Right of Withdrawal and to carry out the Test of Public Support. It would not be appropriate for principal local authorities to take these decisions without being members of the Community Partnership and fully engaged in the process. They must be a member of the Community Partnership in order to have a say.

(15) The community can withdraw from the siting process at any point up until a Test of Public Support is taken. The relevant principal local authorities can either take the decision to withdraw the community from the process themselves or do so after seeking the community's views. If the relevant principal local authorities agree that the decision to withdraw the community from the process should involve the community directly, then the method for seeking the community's view on possible withdrawal from the process will be considered by the Community Partnership as a whole.

(16) NWS can also choose to withdraw from the process. For example, NWS could withdraw for technical reasons, or other reasons which demonstrated there were no longer prospects of finding a suitable site within either the Search Area or Potential Host Community. NWS could also withdraw in order to prioritise available funds across other communities in the siting process. NWS will be transparent in its considerations to withdraw from a community.

(17) Detailed site investigations may take up to 15 years depending on the investigations necessary to understand the geology in an area and be confident that a facility can be designed to safely and securely isolate and contain the radioactive waste. When NWS has sufficient information to satisfy itself that a GDF is viable and the community has indicated it is willing to host it, NWS will need to obtain development consent to build the GDF.

(18) Eventually, if the Right of Withdrawal has not been exercised, or NWS has not withdrawn, the Search Area will be narrowed down until the Community Partnership identifies a specific site and the community which will be directly affected by the facility being on that site.

(19) The relevant principal local authorities must seek a final view from the community, through a Test of Public Support, on whether it is willing to host a GDF before NWS seeks the necessary regulatory approvals and development consent for the construction and operation of a GDF. The Test of Public Support can only take place if all relevant principal local authorities on the Community Partnership agree to it being held. The method for taking the Test of Public Support will be decided by the Community Partnership as a whole. The Community Partnership's view on what mechanisms could be used for this should be set out in the Community Partnership Agreement, which can be updated as views on this develop over time.

(20) The Potential Host Community will be defined using district, or unitary council electoral ward boundaries, depending on the administrative arrangements in place in the area. The Potential Host Community would include all of the wards in which the following would be located:

(a) proposed surface and underground elements of a GDF;

(b) any associated development (as defined under the Planning Act 2008 in England) and any land required to mitigate impacts;

(c) transport links/routes from the GDF site to the nearest port, railhead or primary road network (i.e. out to where minor roads meet the nearest A roads);

(d) direct physical impacts associated with underground investigations, construction and operation of the GDF (identified though environmental impact assessment work carried out to support NWS's engagement with communities and its development consent applications). Only residents in the area that will be directly impacted by the development should have a final say in whether they wish to host a GDF.

It will be the people living in the Potential Host Community, through a Test of Public Support, that will decide whether they want to continue with the process for siting a GDF in the area. As with the Right of Withdrawal, there are currently three main mechanisms that could be used for the Test of Public Support: a local referendum, a formal consultation or statistically representative polling. The Test of Public Support would only be taken after extensive community engagement when the community has had time to ask questions, raise any concerns and learn about a GDF. There will be only one opportunity for a Test of Public Support in each Potential Host Community.

(21) The community's Right of Withdrawal will cease following the Test of Public Support. Once it has been established that the community is willing to host a facility, and NWS, has identified a preferred site, NWS, subject to the Secretary of State's agreement, will proceed with applications for the relevant planning and regulatory consents required for the underground investigations, construction and operation of a GDF.

Progress in siting in the UK

It is fair to say that progress by Nuclear Waste Services (the subsidiary of the Nuclear Decommissioning Authority which is responsible for finding a site for and developing the GDF) has been mixed. Much of the early focus was in the North-West of England, a region with a long nuclear heritage, and consequently a relatively high degree of public acceptance of nuclear and nuclear waste related development. However, finding both a suitable geology, and winning the mind of a host community on that geology, is a challenge.

The most recent account is in NWS's *GDF Report 2024, Protecting People an Our Environment*, detailing progress of the GDF siting process up to 31 March 2024.[56] In 2023, NWS withdrew from the community engagement process in Allerdale, Cumbria, because its analysis showed there was not likely to be enough suitable rock for a GDF. NWS has stressed the need to be transparent in its reasons for withdrawal from a community and to honour any Community Investment Funding commitments already made and in fact Allerdale benefited from funding of over £2.2 million on some 60 local projects. Discussions are proceeding with the Mid Copeland and South Copeland Community Partnerships in Cumbria, and one based around Theddlethorpe in Lincolnshire. All are considering sub-seabed inshore sites, and each have their own issues to be resolved, for example the relative complexity of the West coast geology and the other competing infrastructure projects, such as offshore wind, on the East coast. Studies are proceeding on the deep geology and on the environmental sensitivity, such as local landscape and biodiversity.

What is also mentioned in the GDF Report, albeit very briefly, is the withdrawal in February 2024 of East Riding of Yorkshire Council from the South Holderness Working Group, leading to the Working group being wound down.[57] This came just one month after the formation of the Working Group following a meeting at which local councillors voted 53-1 in favour of a motion calling on the council

[56] https://www.gov.uk/government/publications/gdf-report-2024.
[57] https://www.gov.uk/government/news/nuclear-waste-services-responds-to-councils-withdrawal-from-south-holderness-working-group.

to withdraw.[58] A significant factor was the strong opposition by the local Conservative MP, Graham Stuart, who also then happened to be the Minister fir Energy Security.[59]

Further, in the case of Theddlethorpe, proposals have come from the leaders of Lincolnshire County Council and East Lindsey District Council for an early test of public support to avoid prolonged uncertainty affecting the area.[60] There appears to be a quite concerted anti-GDF cohort of the population in the area, the demographics of which lean towards retired people and seasonal holidaymakers. The Guardian has reported fears the Theddlethorpe may end up on a "shortlist of one" and apparently a gaffe in which the local seaside resort of Skegness was wrongly spelled as "Skegross" on a map did little to engender local support.[61]

The Waste Inventory

Knowledge of the national waste inventory, and which parts of it are destined for geological disposal, are essential for the planning and design of an underground disposal facility. Decisions need to be made as to whether portions of the inventory, such as certain types of intermediate level waste, which may present a lower degree of hazard, should go into a deep repository or whether disposal at shallower depth may be also offer a safe and more cost effective solution.

A potentially difficult question is how to deal with future waste arisings from new nuclear generation facilities, particularly given the ambitions in the UK, France (and other countries) for a nuclear renaissance supporting an expansion of nuclear energy. For proposed GDFs this raises the issue of scale and whether a local community is willing to take the leap of faith of supporting a GDF of an 'as yet' unknown capacity. There is quite a difference in perception in being willing to host a facility to deal with an existing national problem of a known scale, and on the other hand an indeterminant, potentially open-ended range and quantity of wastes.

58 https://world-nuclear-news.org/Articles/Holderness-withdraws-from-UK-repository-siting-pro.

59 https://www.bbc.co.uk/news/uk-england-humber-68233882.

60 https://www.lincolnshire.gov.uk/news/article/1568/leaders-call-for-quicker-end-to-uncertainty-on-theddlethorpe-gdf.

61 https://www.theguardian.com/business/2024/mar/03/itll-be-a-shortlist-of-one-villagers-in-england-fear-nuclear-dump-proposal.

The UK Policy[62] (para. 8.63) lists the radioactive wastes and nuclear materials not yet declared to be wastes which would comprise the inventory for disposal in a GDF:

- HLW arising from reprocessed spent nuclear fuel at Sellafield;
- ILW arising from existing nuclear licensed sites, defence, medical, industrial, research and educational facilities that is not suitable for disposal in near surface facilities;
- the small proportion of LLW that is not suitable for disposal in near surface facilities;
- spent fuel from existing commercial reactors (yet to be declared waste) and from research reactors that is not reprocessed;
- spent fuel (yet to be declared waste) from new nuclear projects (including small modular reactors);
- spent fuel (yet to be declared waste) from advanced modular reactors if it is suitable for disposal in a GDF;
- ILW from new nuclear projects not suitable for disposal in near surface facilities; the plutonium inventory (yet to be declared waste) – either as spent fuel following reuse or in an immobilised form suitable for geological disposal;
- uranium stocks – including that arising from enrichment and fuel fabrication activities and reprocessing activities (yet to be declared waste); and
- irradiated fuel and nuclear materials (yet to be declared waste) from the UK defence programme.

The Policy (para. 8.64) does not anticipate that these categories will change significantly. The assumption is that there will be up to 24 GWe of new nuclear capacity generating spent fuel, through large-scale nuclear power stations, SMRs and AMRs.[63] It is recognised that communities considering hosting a GDF will want to have as clear as possible an understanding of the inventory for disposal before they take a Test of Public Support. If the list were to change significantly then it would need to be discussed with the potential host community and a process for agreeing any future material changes to the categories of waste to be disposed of would need to be agreed before the community took a decision on whether or not it wishes to host a GDF

New nuclear technologies, especially advanced reactors with different forms of fuel and cooling from the existing generation of reactors, seem likely to pose uncertainties and potentially serious difficulties as to the nature of the containment, and quite possibly pre-treatment, which will be required. CoRWM

[62] https://assets.publishing.service.gov.uk/media/6632371769098ded31fca7c1/managing-radioactive-substances-and-nuclear-decommissioning-uk-policy-framework.pdf
[63] Ibid. para. 55.

addressed this issue in depth in its Position Paper, *Development of Small Modular Reactors and Advanced Modular Reactors – Implications for the Management of Higher Activity Wastes and Spent Fuel* in February 2024.[64]

Whilst the UK Government's preference is for a single GDF to take the entire inventory, it acknowledges that in a given host community there might not be sufficient suitable rock or a safety case might not be able to be made for some parts of the inventory.[65] It is not envisaged that a potential host community would be able to pick and choose the inventory it will host.

Retrievability

Disposal of waste implies finality, that there is no intention to retrieve the waste: however that is not to say that retrieval will be impossible. IAEA Safety Guidance notes that while in some states post-closure retrievability is a national requirement, it is important that provision for retrievability should not compromise safety standards, or have an unacceptable effect on the safety or performance of the disposal system and is considered as an "exceptional condition" if occurring in the post-closure period.[66]

Section 22 of the US Nuclear Waste Policy Act requires that any repository be designed so that spent nuclear fuel may be retrieved during an "appropriate period", which appears to equate to the 100 to 300 years prior to repository closure. By comparison, French law requires that waste must be retrievable for the first few hundreds of years, in case a use can be found for it.

There is no hard and fast rule in the UK, but the Waste Policy proceeds on the basis that the objective is disposal of waste, not storage. There may be a "compelling case" for retrieval of emplaced waste during the operational phase of the facility, but will become difficult after permanent closure: and "Permanently closing a GDF at the earliest possible opportunity once operations have ceased provides for greater safety, greater security, and minimises the burden on future generations."[67]

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[64] https://assets.publishing.service.gov.uk/media/65c26c9ca6838e000d49d589/corwm-smr-and-amr-position-paper.pdf.

[65] https://assets.publishing.service.gov.uk/media/6632371769098ded31fca7c1/managing-radioactive-substances-and-nuclear-decommissioning-uk-policy-framework.pdf, para 8.65.

[66] IAEA Safety Standards, *Geological Disposal Facilities for Radioactive Waste*, Specific Safety Guide No. SSG-14, Vienna 2011, paras. 1.1.

[67] https://assets.publishing.service.gov.uk/media/6632371769098ded31fca7c1/managing-radioactive-substances-and-nuclear-decommissioning-uk-policy-framework.pdf., paras 8.75-8.77.

The ability to retrieve waste for the relatively short period that the GDF is operational appears to make sense, from both a safety and resource perspective; the latter such that human knowledge may develop over a period of few hundred years. However, beyond that it can be argued that the ambition of retrievability is a misplaced human desire to control, whereas "…*the involvement of deep geological formations can be characterized as a posthuman task in the sense of decentering humans as permanent 'instances of care and management' in the long run (especially with regard to such disposal systems that should be irreversibly sealed in the future*)."[68]

Transportation

One of the most important factors in siting a GDF is the issue of transportation, both in connection with the construction process and also in transporting the spent fuel and radioactive waste for deposit in the facility once built. In respect of the former, the main impact is likely to be the removal for disposal elsewhere of large quantities of spoil and excavated rock. With regard to the latter, transportation of higher-level radioactive waste is subject to strict regulation, and has occurred over many decades on a regular basis by ships, road and rail, and on occasion by air.

Nonetheless, operation of a GDF, at least in the UK, would result in hundreds of repeated movements, on a frequent basis, over many decades. Those on the proposed transportation route may therefore be expected to have a legitimate concern as to the actual or potential consequences of such transportation. A number of local authorities are members of the organisation, 'Nuclear Free Local Authorities'[69] and may be expected to oppose road or rail movements of higher activity radioactive wastes through their areas: they may well be joined by others as proposed GDF transportation corridors become clearer. The question therefore arises of how such authorities or affected communities fit within the Working with Communities process. The Policy, as noted above, contemplates that the host community will include those hosting transportation links or routes from the GDF site to the nearest port, railhead or primary road network. At the time when the site at Yucca Mountain was being considered, a proposed rail corridor starting in Caliente, Nevada, was proposed and was the subject of environmental impact assessment.[70] The route avoided the most densely

[68] Christiane Schürkmann, *Joining Multiple Collaborations: Toward a Sociomaterial Perspective on Nuclear Waste Management between Society, Technology and Nature*. Worldwide Waste: Journal of Interdisciplinary Studies, 5(1): 3, 1–16 (2022). https://www.whp-journals.co.uk/WW/article/view/1059/622 .

[69] https://www.nuclearpolicy.info/about/member-councils/.

[70] https://www.energy.gov/nepa/eis-0369-supplemental-yucca-mountain-rail-corridor-and-rail-alignment.

populated areas in the Las Vegas valley but was the most challenging route in terms of an engineering and environmental standpoint.

Conclusions

There is a very broad and rich range of literature relating to radioactive waste, social science and anthropology.[71] It is clear that there must be "*a triadic alliance of collaboration*" in which society, technology and nature (the geology) are assembled, nature being an "*unruly collaborator*".[72]

The promoter of a GDF has control over its concept and design, its engineering programming, and the process for obtaining the necessary permits. What the promoter cannot control is the geology and its uncertainties. Many decades of investigation and research, both by boreholes and in underground research facilities, will be necessary to validate that the proposed host geology is sufficiently robust to make an acceptable environmental safety case. During that period there will inevitably be uncertainty, though hopefully this will diminish the longer investigation and analysis go on.

Also, what cannot be controlled, at least in a democratic, community-consent based process, is public sentiment, either in favour of, or against, the proposed GDF. This can be suddenly affected by political factors, either at local or national level, as seen in the USA and in the UK. It must be borne in mind that public support may have to be sustained over a number of years while confirmatory investigations tale place.

Whilst financial inducements, such as support for local projects or investment in infrastructure or costal defences may assist, it may be queried whether these alone will sustain public support without a clear vision – as seems to have been the case in Finland – of the purpose and nature of the project.

It may well be that GDF promoters are naturally inclined to invest more energy and resources in the "hard" aspects, such as engineering and project management which they can control: but it would be very risky not to invest equally deeply in communicating with potential host communities, including understanding fully the underlying social science and learning from experience, both good and bad, in other countries and on different types of infrastructure projects.

[71] See the useful survey in Christiane Schürkmann, *Joining Multiple Collaborations: Toward a Sociomaterial Perspective on Nuclear Waste Management between Society, Technology and Nature*. Worldwide Waste: Journal of Interdisciplinary Studies, 5(1): 3, 1–16 (2022). https://www.whp-journals.co.uk/WW/article/view/1059/622.

[72] Ibid.

What is clear is that very significant funding, time and expertise will need to be invested in the process of finding solutions for permanent disposal solutions for spent fuel and higher activity wastes if a global expansion of nuclear energy is to occur. In those countries where the process has been or is being successful, it can be observed what level of scientific, financial and social collaboration will be needed. In other countries such as the US and UK, history teaches what a fraught and uncertain process it can be. However, the risks for present and future generations of creating high level waste which will sit in surface or near surface stores indefinitely should not be regarded as tolerable.