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Identifying remaining socio-technical challenges at the national level: USA

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Contents

1. Introduction

This report contributes to the InSOTEC research programme's Work Package 1.1 that maps remaining socio-technical challenges to the implementation of geological disposal of radioactive waste across fourteen countries in the EU and North America (www.insotec.eu). The aim of this report is to provide an overview of the current situation of geological disposal of High Level radioactive Waste (HLW) and Spent Nuclear Fuel (SNF) in the USA. In line with this aim the focus is on current activities on the federal level, including brief discussions of the Yucca Mountain programme and WIPP (Waste Isolation Pilot Plant).

Being a desk-based study undertaken from the UK this report relies predominantly on materials available on-line. Hence, we draw primarily on documents produced and published by the actors currently involved with HLW/SNF management in the USA and on academic publications. We thank Daniel Metlay for commenting on draft versions and apologies for not always following his advice. The material gathered has been interpreted in a way underpinned by anti-essentialist, practice focussed, science and technology studies perspectives as developed in, for example, Callon, Barthes and Lascoumes, 2009; Jasanoff, 2004 and Latour, 2005. Since the ambition of this report is primarily descriptive we do not engage in explicit theoretical discussions.

The format of the report is that of an overview, not a narrative. We begin with a brief outline of the current state of geological disposal of HLW and SNF in USA, this is followed by a brief timeline focussing on events interesting in relation to the InSOTEC context of international comparison. The next section introduces the central actors involved with HLW/SNF geological disposal and it closes with a list. After this we outline the recent work of the Blue Ribbon Commission on America's Nuclear Future (BRC) and the senate bill based on its recommendation, introduced by Jeff Bingaman. Section four outlines the Yucca Mountain programme, currently in a state of suspension as the termination attempted by the DOE (Department of Energy) is contested in the courts. The report presents two different analyses of the programme: a compilation of critical studies undertaken when it was in operation and a post-termination examination by the Nuclear Waste Technical Review Board (NWTRB). Section five looks briefly at WIPP, an example of a successful programme for geological disposal of trans-uranic radioactive waste (not HLW or SNF) that began operations in 1999. Finally, we offer some closing remarks taking into consideration the on-going debate among the actors involved.

2. Current situation

Currently the US senate is processing a bill introduced by New Mexico Senator Jeff Bingaman that would implement the recommendations made by the BRC in their final report presented to the Secretary of Energy on January 26 2012. The BRC was appointed in 2010 to formulate a new strategy for geological disposal of HLW/SNF. The need for a new strategy followed from the DOE's termination of the Yucca Mountain programme, in March 2010 they filed a motion to withdraw the license application for a geological repository (DOE, 2010). In the US such a move does not mean that the Yucca Mountain programme has been permanently shut down, as the decision to terminate the programme is being challenged in law courts. However, it does mean that the USA is facing the challenge of agreeing on a long-term strategy for safe permanent disposal of HLW/SNF. Whatever form a new policy will take, restarting the Yucca Mountain programme, or looking elsewhere, political decisions have to be made. In the following two sub-sections the current situation is detailed historically and organisationally.

2.1 Time line

On the 12 of September 2012 the US Senate Committee on Energy and Natural Resources conducted hearings on a bill introduced by its chairman Senator Jeff Bingaman from the State of New Mexico. The bill S.3469 Nuclear Waste Administration Act of 2012 was introduced to the Senate on August 1. The fact that the bill has no cosponsors is taken as a sign of how difficult it is to reach any agreements on this issue in the US legislature. The American Institute of Physics (AIP) writes in its on-line news bulletin:

> *Indicative of how deeply troublesome it has been to find agreement on the handling of nuclear waste was the breakdown of a plan to include Lisa Murkowski (R-AK), Dianne Feinstein (D-CA), and Lamar Alexander (R-TN) as original cosponsors of the legislation. These senators are the chairs or ranking members of the Senate authorization and appropriations committees with primary jurisdiction over nuclear waste. The four senators were unable to reach agreement on a legislative mechanism to ensure that a temporary site does not become a permanent storage facility Almost three months after the bill was introduced, it has no sponsor besides its author. "With time running out in this Congress, we agreed that I should go ahead and introduce the bill as it stands, and hold this hearing on the bill, and leave it to the next Congress to continue working on the issue," Bingaman said in his opening remarks at the September 12 hearing. (Jones, 2012).*

This quote shows both how contentious the issue of nuclear waste disposal is and that it will take some time before the US has adopted a new strategy for how to permanently dispose of the existing and future HLW/SNF. The report concludes that the review of the bill in the Committee was generally positive and that it will be up to the next congress to decide how to proceed.

Bingaman's bill is based on the recommendations put forward in the BRC report that concluded two years of study. The BRC's work began on the 29th of January 2010, about a month before the withdrawal of the license application for a deep geological disposal facility at Yucca Mountain on March 3 (DOE, 2010). The currently suspended, possibly discontinued, Yucca Mountain programme became the only plan for HLW/SNF disposal in the USA through the 1987 amendments to the Nuclear Waste Policy Act (NWPA) of 1982. The original Act established the federal government's responsibility to provide for permanent disposal of HLW and SNF, with the waste producers bearing the cost. The 1987 amendments specified that only one site would be investigated: Yucca Mountain in the State of Nevada. The 1982 and 1987 laws provided, at the time of establishment, a legal framework for the long-term management of HLW and SNF in the US. A 1985 Mission Plan from the DOE, produced in response to the 1982 act through a process of public consultation, exudes enthusiasm and confidence, anticipating disposal operations to start by January 31st 1998 (DOE, 1985).

These are some of the events leading up to the present situation, a timeline premised on the present state of uncertainty can be very basic:

- 2012 Committee on Energy and Natural Resources hearing on bill S.3469 Nuclear Administration Act of 2012, introduced by senator Bingaman, implementing the BRC's eight recommendations (with some differences).

- 2012 BRC reports to the Secretary of Energy making eight specific recommendations.

- 2010 The DOE submits a motion to withdraw the pending licence application for a SNF/HLW repository in Yucca Mountain to the Atomic Safety and Licensing Board

- 1987 Amendments to the NWPA establishes Yucca Mountain as the only site to be investigated for geological disposal of civilian HLW/SNF.

- 1982 The NWPA (Nuclear Waste Policy Act) regulates the federal government's responsibility for HLW/SNF disposal.

- 1977 The NRC (Nuclear Regulatory Commission) declares that it will not issue licences for new nuclear reactors if there is no safe waste disposal plan.

- 1969 The Atomic Energy Commission conducts experiments with SNF in abandoned salt mine in Lyons, Kansas.

- 1957 The Atomic Energy Commission recommends geological disposal in salt for HLW and SNF.

This timeline traces the current situation backwards in time, showing the failure of the long running Yucca Mountain programme to deliver according to plan, in spite of backing from experts, federal government and industry. This is a similar situation of failure to implement HLW/SNF geological disposal as we find in other countries; however, the path towards it is unique. For example, the actors involved display considerable continuity over time, with the DOE and the NRC playing major roles.

2.2 Actors

At the centre of any geological disposal programme in the past, present and foreseeable future is the DOE (US Department of Energy), an agency of the federal government. The DOE is in charge of managing all nuclear waste in the USA and leads on the geological disposal of HLW/SNF. Searching for information we found the Office of Environmental Management (OEM), created in 1989 and responsible for nuclear environmental restoration, waste management, technology development, and facility transition and management (http://www.em.doe.gov/Pages/History.aspx). The OEM states its mission as being 'to cleanup the environmental legacy of nuclear weapons production and nuclear energy research' (http://www.em.doe.gov/Pages/Mission.aspx). With responsibility for all categories of radioactive waste from military and research sources the OEM works with a range of different types of disposal. For the purpose of the present report the most relevant activity it the geological disposal of trans-uranic (TRU) waste at WIPP and the interim storage of SNF in three locations: the Hanford Site in Washington, the Idaho National Laboratory and the Savannah River Site in South Carolina (http://www.em.doe.gov/Pages/spentfuel.aspx?wmdiid=1). WIPP is a geological repository mined in a formation of rock salt, with the mission is to provide permanent disposal for TRU waste from defence activities. No high-level waste or spent fuel will be placed there (http://www.em.doe.gov/bemr/BEMRSites/wipp.aspx). HLW and SNF generated by military and research activities and owned by the federal state are currently managed in interim storage, by the OEM, while awaiting permanent disposal in a geological repository (it comprises 2400 metric tonnes of heavy metal). However, the main bulk of HLW is the SNF created by civilian nuclear power plants providing the US with energy. Currently there is no information in the public on-line sphere about what the DOE is doing in relation to HLW/SNF geological disposal. We understand this to be a consequence of the uncertain policy situation.

Another important actor is the nuclear industry, it is the main producer of SNF (68000 metric tonnes to date) and it is responsible for its safe keeping at the power plants of origin, which is currently how all civilian SNF in the USA is managed. In addition nuclear power companies continue to pay for geological disposal, in spite of the current lack of implementation strategy. Nuclear power businesses across the USA come together in the NEI (Nuclear Energy Institute) an organisation engaging with both the national and global policy-making processes. The NEI's objective is to 'ensure the formation of policies that promote the beneficial uses of nuclear energy and technologies in the United States and around the world' (http://www.nei.org/aboutnei/, 10/8/2012). The NEI opposed the closing of the Yucca Mountain programme and challenged it in the courts. In a press release the NEI expresses disappointment over a recent court ruling that their lawsuit – filed in response to the DOE's motion to withdraw the license application before the NRC had ruled on it – be held in 'abeyance for up to four months pending congressional action on fiscal year 2013 appropriations related to the federal government's nuclear waste management program' (NEI, 2012). Although the industry has been able to manage SNF safely it was never the intent that they would be responsible for long-term storage, or a final solution. The responsibility for long-term storage and final disposal resides with the federal government and with the termination of the Yucca Mountain programme industry dissatisfaction with the timetable failure (the federal government had promised to begin taking waste from power plants in 1998) has been compounded by uncertainty about what the federal government is going to do.

The regulatory oversight of the safety of HLW/SNF management is the responsibility of the NRC (US Nuclear Regulatory Commission). Established by the Energy Reorganization Act of 1974 its mandate is to independently regulate commercial uses of nuclear material, including nuclear power. The NRC is headed by five Commissioners (no more than three from the same political party), nominated by the President and confirmed by the Senate for staggered five-year terms. The NRC formulates policies and regulations governing nuclear reactor and materials safety; issues orders to licensees and adjudicates legal matters brought before it. One member of the Commission is designated by the president to serve as Chairman and official spokesperson. With regard to HLW/SNF geological disposal the latest update on the NRC website from September 2011 says that:

> *On October 1, 2010, the NRC began orderly closure of its Yucca Mountain activities. As part of the orderly closure, the NRC staff prepared three technical evaluation reports. /…/The NRC's 'non-sensitive Yucca Mountain-related documents' are being preserved and made available to the public as part of the NRC staff's activities to retain the accumulated knowledge and experience gained as a result of its Yucca Mountain-related activities. (http://www.nrc.gov/waste/hlw-disposal.html, 25/7/2012)*

The NRC website also informs the public about what is currently done with SNF:

All U.S. nuclear power plants store spent nuclear fuel in "spent fuel pools." These pools are robust constructions made of reinforced concrete several feet thick, with steel liners. The water is typically about 40 feet deep, and serves both to shield the radiation and cool the rods. As the pools near capacity, utilities move some of the older spent fuel into "dry cask" storage. Fuel is typically cooled at least 5 years in the pool before transfer to cask. NRC has authorized transfer as early as 3 years; the industry norm is about 10 years. The NRC believes spent fuel pools and dry casks both provide adequate protection of the public health and safety and the environment. Therefore there is no pressing safety or security reason to mandate earlier transfer of fuel from pool to cask. (Spent Fuel Storage in Pools and Dry Casks: Key Points and Questions & Answers, http://www.nrc.gov/waste/spent-fuel-storage/faqs.html, 31/7/2012)

If the legislating bodies adopt a new strategy the NRC will develop the policies and regulations needed to implement it. A more urgent question for the NRC is to amend the 'Waste Confidence Decision' from 2010 that declared present wet and dry storage of SNF at power generating facilities to be safe in the interim period, before it can be disposed of in a geological repository. In 2012 a court found that some of the aspects of the 2010 decision did not satisfy the legal obligations (New York v. NRC, 681 F.3d 471, D.C. Cir. 2012). In response to this ruling the NRC ceased licensing activities that depended on the Waste Confidence decision and created a new directorate to oversee the drafting of a new 'Waste Confidence Environmental Impact Statement and Rule' by 2014 (http://www.nrc.gov/waste/spent-fuel-storage/wcd.html).

The NRC's mandate pertains to commercial nuclear facilities, a wider regulatory remit is that of the US Environmental Protection Agency (EPA) which is responsible for all radioactive waste management through setting 'public health and environmental radiation protection standards, provide information to assist waste generators, and provide information to the general public' (www.epa.gov/radiation/waste-management-overview.html, 10/8/2012). The EPA regulates all radiation that could reach humans and the environment. The agency sets protective limits of radioactivity for air, water and soil. The NRC uses EPA's standards to develop regulations for commercial nuclear facilities (http://www.epa.gov/radiation/docs/402-f-01-021.pdf). EPA conducts research on both the risks of exposure occurring and the risks from having been exposed. The EPA website also provides information on its roles in relation to the Yucca Mountain programme and the WIPP operations.

The actors directly involved in the on-going management of waste and with implementing final geological disposal are also provided with expert knowledge and advice from scientific organisations. One expert body is the NWTRB (US Nuclear Waste Technical Review Board) which introduces itself as 'an independent agency of the U.S. Federal Government' (http://www.nwtrb.gov/, 6/8/2012). It has as its sole purpose 'to provide independent scientific and technical oversight of the Department of Energy's program for managing and disposing of high-level radioactive waste and spent nuclear fuel' (op cit). Created through the 1987 Amendments to the Nuclear Waste Policy Act the NWTRB's responsibility for conducting on-going scientific review of the DOE's activities continues, regardless of the strategy adopted. The NWTRB reports to Congress and the Secretary of Energy at least two times per year. The termination of the Yucca Mountain programme is reflected in the NWTRB's mission for 2010-2011, with one important task concerning the waste now stranded, temporarily without destination, from nuclear facilities that have been shut down. The report, soon to be published on the NWTRB website, can be expected to outline the management alternatives under consideration and the technical issues that need to be resolved. Another task brought to the forefront by the Yucca Mountain closure was the evaluation of very long-term dry storage, as it was deemed likely that commercial SNF would remain in storage longer than previously anticipated, a report on this was published in 2010 and is available on the NWTRB website (NTRWB, 2010). The NWTRB interacted with the BRC in various ways, for example, by updating a 2009 survey of national programmes for management of HLW/SNF (NWTRB 2009 and 2011). The NWTRB has also published analyses of the Yucca Mountain programme and reflected on the lessons that can be drawn from it, we will look closer at these documents later on.

Another scientific actor is the NRSB (Nuclear and Radiation Studies Board), part of the National Academy of Sciences. Its mission is to '(1) provide an open forum for discussion, and (2) organize and oversee studies on safety, security, technical efficacy, and other policy and societal issues arising from the application of nuclear and radiation-based technologies' (dels.nas.edu/global/nrsb/About-Us, 10/8/2012). The NRSB undertakes scientific study and publishes peer reviewed reports. A 2001 report on geological disposal declares it to be the only solution providing long-term safety and that the difficulties encountered worldwide with regard to implementation are societal, not technical (NRSB, 2001)

The work with safe HLW/SNF management continues regardless of the termination of the Yucca Mountain programme. However, actors and activities are not coordinated in relation to the long-term goal of deep geological disposal unless a national strategy, replacing or resuming the Yucca Mountain programme, is adopted. A proposal of a strategy has been created by the BRC, a 15 member commission that was tasked with conducting a comprehensive review of policies for managing the 'back end of the nuclear fuel cycle' (www.brc.gov/index.php?q=page/about-commission, 27/7/2012) and recommend a new strategy to the federal government. The BRC was organised in three subcommittees focussing on: reactor and fuel cycle technology; transportation and storage and disposal. Membership of the three overlapped in order to ensure effective communication and there were cross-cutting issues addressed by all. The BRC emphasised that they were not a siting commission and would not recommend any specific location for any part of the waste disposal system, nor would they comment on the future use of nuclear energy. In the next section we look closer at the BRC's recommendations.

In the document archives created by the BRC we can see that not all parties interested in the issue of geological disposal are in favour of nuclear power. The NIRS (Nuclear Information and Resource Service) is an anti-nuclear activist network on the national level. It describes itself as 'the information and networking center for citizens and environmental organizations concerned about nuclear power, radioactive waste, radiation, and sustainable energy issues' (http://www.nirs.org/about/nirs.htm, 10/8/2012). A NIRS member submitted a critical comment to the BRC, pointing out the exclusion of critics of nuclear power from the Board and the failure to take the entire nuclear power chain into consideration, arguing that the only way to ensure absolute safety from the hazards posed by nuclear waste is to stop producing it (Olson 2010). In addition to the NIRS the Sierra Club, with a much broader agenda relating to nature conservation is also categorically opposed to nuclear power in its entirety (www.sierraclub.org/nuclear/, 10/8/2012).

List of actors:
DOE (US Department of Energy) federal government
OEM (Office of Environmental Management) DOE branch
NEI (Nuclear Energy Industry) body representing the nuclear industry
NRC (Nuclear Regulatory Commission) regulates nuclear industry
EPA (Environmental Protection Agency) radiation safety regulator
NWTRB (Nuclear Waste Technical Review Board) independent science advisory body

NRSB (Nuclear and Radiation Studies Board) scientific body
NIRS (Nuclear Information and Resource Service) anti-nuclear organisation
Sierra Club anti-nuclear nature conservation organisation

3. The BRC on America's Nuclear Future

Senator Bingaman's bill, mentioned in the previous, is based on the eight recommendations made by the BRC. In this section we take a closer look at the BRC report and identify the differences between it and the senator's bill.

The BRC's final report starts with stating that the Yucca Mountain project and the policy of pursuing it, have failed. Emphasising the cost of not having a strategy for the 'back end of the nuclear fuel cycle' the BRC stresses the urgent need for a new strategy, not only because of the costs, but also to fulfil an ethical obligation to not burden future generations. Noting that any strategy needs to keep as many options as possible open for future revisions the BRC lists the eight key elements of their proposal:

1. A new, consent-based approach to siting future nuclear waste management facilities.
2. A new organization dedicated solely to implementing the waste management program and empowered with the authority and resources to succeed.
3. Access to the funds nuclear utility ratepayers are providing for the purpose of nuclear waste management.
4. Prompt efforts to develop one or more geologic disposal facilities.
5. Prompt efforts to develop one or more consolidated storage facilities.
6. Prompt efforts to prepare for the eventual large-scale transport of spent nuclear fuel and high-level waste to consolidated storage and disposal facilities when such facilities become available.
7. Support for continued U.S. innovation in nuclear energy technology and for workforce development.
8. Active U.S. leadership in international efforts to address safety, waste management, non-proliferation, and security concerns. (BRC, 2012)

According to the AIP Bingaman's bill differs from the BRC's recommendations on three important points (Jones, 2012). Firstly, it proposes that a new Nuclear Waste Agency would be a federal agency, instead of a chartered corporation. The bill also retains the existing link between a permanent geological repository and consolidated storage, prohibiting the latter until a site has been decided upon for the former, the BRC wanted to disconnect the two. A third difference is the size and composition of a proposed Nuclear Waste Oversight Board.

In a testimony at the Senate Committee hearing on Bingaman's bill the NEI spokesman reiterated the industry's criticism of the termination of the Yucca Mountain project, but the emphasis was on supporting the BRCs recommendations and Bingaman's bill (http://www.nei.org/publicpolicy/congressionaltestimony/testimony-to-the-senate-energy-and-natural-resources-committee/). The NEI testimony mentioned the need for consolidated interim storage, emphasising that the federal government is committed to take the waste, regardless of where a geological disposal facility will be sited and that waste needs to be removed from power plants urgently. The need to create a dedicated organisation was also discussed in some depth, with the NEI supporting the proposal outlined by the BRC of a federal corporation removed from the political appointment process. NEI also spoke in support of the BRC's proposals for securing access to funding and adopting a consent-based approach to siting.

The positive response to Bingaman's bill is not unexpected, considering that the BRC did point out that all the things brought together in the recommendations had been discussed before. The commission saw its contribution as being to combine the elements in a coherent strategy and identify the necessary legislative changes. The BRC proposal is also very similar to new policies developed in other countries, most recently in the UK and Canada. Like the NWMO (Nuclear Waste Management Organisation) in Canada and CoRWM (Committee for Radioactive Waste Management) in the UK, the BRC advocates a voluntaristic siting process, proposing that one of the tasks of the new dedicated body would be to:

> *Encourage expressions of interest from a large variety of communities that have potentially suitable sites – As these communities become engaged in the process, the implementing organization must be flexible enough not to force the issue of consent while also being fully prepared to take advantage of promising opportunities when they arise. (BRC, 2012:ix)*

The idea of voluntaristic siting is not new to the US discussions, but perhaps this, like other ideas resurrected by the BRC, are more in tune with society now than what has historically been the case.

In similarity with bodies created in other countries to rethink HLW/SNF policies the BRC had the ambition to conduct a comprehensive, open and inclusive review. To accomplish this they listened to thousands of individuals and organisations in formal hearings and on site visits, they also received written letters and electronically submitted comments. They visited interested communities across the country and other countries in order to learn. The BRC were reminded of the importance of unanticipated physical events as the Fukushima nuclear power plant was seriously damaged by a devastating earthquake and associated tsunami hitting the east coast of Japan. The report acknowledges that the BRC were 'acutely aware that the Fukushima disaster has altered the technical, social, and political context into which our findings and recommendations are being released' (BRC, 2012: 2). The BRC also recognises the changing role of the USA in the world, announcing their awareness 'of the changing and far from certain global outlook for nuclear power and the effects of America's diminishing ability to influence where and how nuclear energy is used' (op cit). This could be interpreted against the backdrop of the nuclear programme in Iran that has caused significant international tension. However, the most important factor for the BRC's existence and activities were the termination of the Yucca Mountain programme.

4. The end of the Yucca Mountain programme?

Activities began at Yucca Mountain in 1977 when the location became one of several candidate sites investigated for geological disposal. Ten years later, 1987, the US congress legislated that Yucca Mountain would be the only site investigated and from then on all US research on HLW/SNF deep geological disposal centred there. From 1977 to 2000 the scientific and technical research focussed on characterising the site, the investigations involved geologists and material scientists and the aim was to learn about the site and the requirements of engineered barriers. The site characterisation phase formally ended in 2002, but from 2000 the focus had shifted to license applications and related engineering projections. In July 2002 Congress instructed the DOE to apply for a license to construct a repository. From then on a key task was to use the scientific and engineering knowledge to develop computer models that could be used to demonstrate the safety of the disposal facility. The license application was submitted in 2008, but withdrawn in March 2010 and in October the same year directives were given for an orderly close down of the Yucca Mountain programme.

4.1 Critical scrutiny

The Yucca Mountain programme was controversial from the outset and many actors wanted to stop it, this also meant that many aspects of the programme became subjected to critical scrutiny by experts in different disciplines. One example of critical academic study is Murphy's (2006) discussion of problems arising in relation to the regulatory framework. It began in 1974 when the NRC was established as the licensing authority, later the 1982 NWPA set the national framework and specified the roles of principal agencies involved. The DOE was to determine site suitability and then develop, build and operate the facility according site selection criteria of 1984 and suitability criteria specified in 2001. The EPA was to set standards to assure the protection of the public and the environment. Over time the seemingly straightforward framework was found to be in need of renegotiation as set criteria and general guidelines did not work. Murphy describes how the EPA's initial standard of demonstrating safety for ten thousand years clashed with NRC's requirement of one thousand years and the National Academy of Sciences pointed out that scientifically one million years would be more appropriate. Eventually the 2002 DOE environmental impact statement addressed time scales of four hundred and six hundred thousand years. Another problem discussed by Murphy is the assessment of effect. Radiation exposure is a complex issue involving the concentration, release, dose and risk of effect. Again the EPA standards and the DOE's ability diverged, in this case the NRC agreed with EPA on the importance of groundwater protection, meaning that the measurement of risk to individuals had to change, from a focus on release to individual dose. Spatial configurations also became an issue of contention as the EPA expanded the exclusion zone to agree with DOE assessments of ground water movement, but this was challenged by the National Academy of Sciences who argued that individuals living along the path of contaminated ground water would be at risk, regardless of the boundaries of an exclusion zone, subsequently the NRC specified a contamination level for ground water. According to Murphy the pattern with regulatory agencies working at cross-purposes remained over time.

The Yucca Mountain programme may also have lacked sufficient local support to overcome the negative attitude of the State of Nevada. The fact that nobody lives at Yucca Mountain itself, at one point in time, made it possible for the State of Nevada to invent a new administrative territory, 'Bullfrog County' with zero inhabitants and maximum property tax, in order to obtain additional funds from the federal government (Titus, 1990). The measure was successful in its purpose to obstruct the programme, but eventually had to be abandoned when it was challenged in court.

In addition to regulatory complications and opposition from the State the Yucca Mountain programme encountered physical challenges. Applegate (2006) describes the site in detail, starting with the volcanic creation of Yucca Mountain as a mountain made of welded tuff, a hard and brittle material in which the repository was to sit above the water table. For a long time the DOE assumed that water percolated slowly through the tuff and would take thousands of years to move from the earth surface to the repository, but the discovery of radionuclides from nuclear weapons tests in the1950s in water at the depth of the repository contradicted this. Thus the DOE learned about 'fracture flow' and its importance in tuff. Below the repository zeolite minerals in unwelded tuff were expected to slow down the release of radionuclides from the repository, however, this would only work for some radionuclides, others attach to small particles called colloids for travel and when water flows through fractures in the rock adsorption would not happen. These and other discoveries about the rock led the DOE to rely more on engineering to provide barriers preventing the release of radioactivity from the repository, according to Applegate.

Engineering barriers for HLW/SNF deep geological repository is not a simple task, an interdisciplinary anthology from 2006 (MacFarlane and Ewing) dedicates an entire section of four chapters, to the issue. The first of these chapters discusses the cladding of spent nuclear fuel with zirconium alloy (Siegman, 2006). We learn that this cladding, intended to secure the integrity of the radioactive material over long time, had been prone to problems as it could become perforated. Another chapter discusses vitrification, the conversion of the waste into glass (Lutze, 2006). This is a process used to stabilise the liquid waste generated in reprocessing of spent fuel. Due to the decision not to reprocess spent fuel the USA does not routinely produce more reprocessing waste, but that generated by the military in the past awaits treatment and disposal. A third chapter discusses ceramics as an alternative to vitrification, created at lower temperatures (Bourcier and Sickafus, 2006). The waste form is one part of the engineered barriers and another part is the container. The main issue concerning containers for geological disposal is the risk of corrosion, which depends on the geological environment. The repository planned at Yucca Mountain was understood to be in a dry geological zone, above the water table and in an arid climate. Little water was expected to reach the waste containers, hence, many types of metal were possible. According to Shoesmith (2006) the waste packages for Yucca Mountain were to have a double shell, the inner layer made of stainless steel and the outer a nickel alloy. Extensive studies explored every aspect of this design, eventually satisfying the programme that it would be the most resistant and durable. Whether the containers would have performed as expected will never be known, nor do we know if this will be the design used in future repositories. In addition to the waste form and waste packaging container the Yucca Mountain design also envisaged a 'drip shield'. Upon discovering that the tuff was not as dry as expected the engineers invented a shield that would protect the waste containers from water percolating through the mountain causing the containers to corrode. Stahl (2006) describes the drip shield as an 'inverted "U" fabricated from a fifteen-millimetre-thick rolled plate, which has attached to it vertical stiffeners, lifting lugs, and end members' (Stahl, 2006: 302). Made of titanium the interlocking drip shields would be put in place before the closure of the repository and could be covered with backfill.

The technical difficulties arsing in the Yucca Mountain programme were not insurmountable, it was political resistance that brought it to a halt. Having reached agreement with Nevada senator Harry Reid, in 2010 president Obama instructed the Secretary of Energy to terminate the programme and the DOE filed a motion to withdraw the license application it had submitted in 2008. This move has not been universally accepted, a lot of effort and money has gone into the programme and many actors stand to lose a lot if it does not resume. However, at the present moment in time the Yucca Mountain programme is treated as terminated by the US government. This has led to the NWTRB producing reports summing up and analysing the entire programme, in order to learn for the future.

4.2 Learning from failure

The NWTRB was tasked with evaluating and analysing the Yucca Mountain programme after its termination in 2010. One of their two reports from 2011 sums up lessons learned about geological disposal from the many years of exploratory work at the site. Below we take a brief look at some of the conclusions about the science and organisation of the Yucca Mountain programme.

According to the NWTRB the research at Yucca Mountain advanced the understanding of the movement of water in that type of rock in the climatic region at hand. Scientists could combine laboratory, field and analytical methods to develop models for a range of processes that allowed them to test hypotheses. Temperature control was an important issue, since HLW/SNF generates heat it is necessary but difficult, to decide for what temperature a repository would be design for. A critical issue is whether to try to ensure that the heat in the facility remains below the boiling point of water, or to use the heat to prevent water from coming close to the waste containers. Reflecting on the geological knowledge gained the report also discusses surprises, stating that as underground rock is obviously hidden from view '[U]nforeseen geologic features and conditions can greatly affect the cost, schedule, modelling, safety of workers, and performance of the repository' (NWTRB, 2011a: 29). One surprise was that the assumed dryness of the zone above the water table in the unsaturated zone had been over-estimated, there was more water than expected. That surprises prove previous assumptions to be wrong does not mean failure, here the NWTRB points to WIPP, saying that 'Reasonable engineering accommodation to site-characterization reality worked for WIPP, just as a robust container may well have worked for Yucca Mountain' (NWTRB, 2011a: 30, original emphasis). This is a most interesting discussion underlining that sites cannot be exhaustively known before physical investigation. Arguably both WIPP and Yucca Mountain demonstrated that initial geological hypotheses were wrong about the actual characteristics of the respective rock strata, but that did not prevent repository construction to go ahead at Carlsbad.

The need for a system approach, modelling all aspects together – waste acceptance, storage, handling, transportation, packaging and emplacement – is emphasised in the NWTRB report. This is deemed to have failed in the Yucca Mountain programme; although such an approach was developed it was adopted too late in the process and terminated too early. The NWTRB states that: 'Future programs must take integration of the entire system (including reprocessing and recycling, if undertaken) into account at the outset and must maintain that perspective thereafter' (NWTRB, 2011a: vi, original emphasis). It is noted that the failure to treat HLW/SNF disposal as a total system corresponded to the geographically distributed organisation. The scientists and engineers who focussed on the repository were stationed in Las Vegas and in Denver, while those responsible for waste acceptance and transportation were in Washington DC. The OCRWM (Office of Civilian Radioactive Waste Management), the DOE branch in charge of the programme, headquarters were located in Washington, but most of the employees were in Las Vegas. There were also intellectual divergences between the many independent groups of scientists, separated by discipline as well as location. This fragmentation of the programme is understood to have increased when utility companies began to sue the DOE because they were not accepting HLW/SNF, which there were legally obliged to do.

One of the dimensions of integration is probabilistic simulation modelling, understood to have an important role to play for predicting 'quantitatively the long-term performance of a geologic repository' (NWTRB, 2011: 48). A probabilistic model was developed and used in the programme called Total System Performance Assessment (TSPA) and it went through a number of iterations. The last iteration was the most sophisticated and the NWTRB thinks it 'represented the culmination of the most thorough study of the performance of a geologic repository for high-activity waste ever performed by U.S. scientists and engineers' (NWTRB, 2011: 48). This version of the model, TSPA-LA (License Application), had as its major components: models of the waste; the engineered and the natural barrier systems, and the biosphere. Scenarios included early failure of engineered barriers as well as seismic events. The period simulated by the model was extended from 20,000 years in the early versions, to one million years in the final versions. The report concludes that 'TSPA demonstrated that probabilistic dynamic modelling of large, complex natural and engineered systems can be performed' (NWTRB, 2011a: 49). The modelling is considered to have been successful in that it 'pushed the state of the art to higher levels, including (in selected cases) explicit treatment of uncertainties associated with models and abstractions, assessment and propagation of parametric uncertainties and separation of uncertainty resulting from the natural variability of physical phenomena (aleatory uncertainty) and knowledge-based uncertainty (epistemic uncertainty)' (NWTRB, 2011a: 50).

The NWTRB also thinks that the US nuclear waste community ought to learn from the nuclear power industry to perform, maintain and update PRAs (Probabilistic Risk Assessment) on a regular basis. PRAs are considered more meaningful that federal regulation as they not only quantify risk, but also rank order the contributing factors. The report also compares favourably the nuclear industry's more transparent calculation of risk as probability relative different dose levels to the 'probability weighted doses' used in the Yucca Mountain programme. The NWTRB's report on the Yucca Mountain programme informed the BRC's conclusions about the failures of the DOE to implement geological disposal. It is clear that a new implementing organisation will have to do things differently.

5. The succes of WIPP

The most intriguing aspect of geological disposal in the USA is not the failure at Yucca Mountain (which mirrors the experiences in many other countries), but the success of WIPP which is the world's only currently operating facility for geological disposal of nuclear waste, located in Carlsbad, New Mexico. WIPP emplaces transuranic (TRU) waste, comprising contaminated objects, e.g. rags, clothes, soil and sludge from military operations, in salt beds deep underground. The waste accepted is categorised as either Contact-Handled (CH) or Remote-Handled (RH) (Why WIPP, 2007). CH waste can be manually handled without further shielding than the container it is packaged in while RH needs extra shielding to protect WIPP workers. WIPP is scheduled to receive the final shipments in 2033, where after it will be permanently closed and the surface facilities decommissioned by 2039.

WIPP opened in 1999 after decades of controversy and political manoeuvring. According to their own chronology detailed on the WIPP website the story began in 1957 when the National Academy of Sciences settled on salt deposits as the best geological material to dispose of radioactive waste (WIPP Chronology, 2007). Then it took almost 20 years until a 1974 decision of the US Atomic Energy Commission to explore a salt bed close to the town of Carlsbad in New Mexico. From then on the chronology fills up with Congress and the DOE pressing on with applications for a range of permits and challenges posed to them by various actors within the state of New Mexico. Lawsuits and injunctions follow each other, interspersed by new legislation until a 1999 court ruling makes it possible to begin shipping waste into the, by then finished facility. Since 1999 WIPP has been accepting TRU waste from military facilities across the USA, enabling the closure of interim storages in other places. While WIPP's own chronology focuses on the events and institutional actions which hindered or helped opening the plant, a different focus is provided in a book by Chuck McCutcheon (2002). Focussing on the political wrangling that finally brought WIPP into action, McCutcheon begins with the same event, but talks about actions undertaken by individuals, e.g. then New Mexico attorney general, Jeff Bingaman, filing a lawsuit alleging violations of state laws by the DOE in 1982 and a federal government energy secretary, James Watkins, announcing an indefinite delay in 1989.

Obviously WIPP's success did not come easily, controversy surrounded all aspects of the construction of the facility and it is not immediately obvious exactly why WIPP was realised when Yucca Mountain failed. Trying to identify the key to WIPP's success Eriksson and Dials (no date) note that it took considerable time and effort to open the facility and that the mission changed, from being a repository for both TRU and HLW to accept only the former. One feature identified as critical is the 'long-standing willingness among local politicians and residents to host a deep geologic repository for long-lived radioactive waste in their backyard' (Eriksson and Dials, no date: 3). Eriksson and Dials remark that the WIPP project has resulted in DOE sponsored socioeconomic development in the locality and the region. The establishment of a local field office, CAO (Carlsbad Area Office), is considered pivotal. The CAO was able to lead on public engagement and to decide which issues it was meaningful to address at different points in time in a process called the Systems Priorization Method (SPM). The SPM enabled thorough assessment of the scientific activities that underpinned the development of the permit applications submitted. It also made the process transparent and traceable, facilitating non-DOE ownership of the process and following from this wider support. A further aspect of great importance was the notion that disposing of all TRU waste underground in WIPP would reduce the risk of radiation to people in the region since, at the time, substantial amounts of waste was stored temporarily in military facilities over-ground in the state of New Mexico. The initial acceptance of WIPP is also understood to have depended on the merits of rock salt as a material efficient for containment and isolation of radionuclides. The EPA is also perceived to have demonstrated independence and strength as a regulator, contributing to the trust in the process. In conclusion Eriksson and Dials state that a number of interlinked factors brought WIPP into being, and although broad its acceptance was not total. According to Eriksson and Dials five features were critical for the success of WIPP:

- A strong independent regulator;
- A regulatory framework that was widely perceived to protect public health and the environment;
- A willing host community;
- A simple, stable, robust, and generically highly regarded host rock, i.e., bedded salt; and
- An open siting, site characterisation, repository development, certification and recertification process with regularly scheduled opportunities for information exchanges with affected and interested parties, including (a) prompt responses to non-United States (U.S.) Department of Energy (DOE) concerns and (b) transparency/traceability of external input into, and the logic behind, the DOE's decision-making process. (Eriksson and Dials, no date: 1)

WIPP's local support is also discussed by McCutcheon (2002) who notes that the idea of siting a geological disposal facility in Carlsbad came from actors within the community. Throughout the development process prominent figures in the local community were advocating for WIPP and challenging the state legislators opposing it. A recent paper on WIPP, prepared for the BRC, also identifies the 'empowerment' of the state of New Mexico in relation to the establishment of WIPP as contributing to its success (Moore, 2011). Moore argues that the WIPP project was, for many years, controversial because DOE was both operator and regulator; this self-regulation was a major cause of concern. When this was changed by designating the EPA and the State of New Mexico regulators, these concerns were alleviated. The further involvement of the state in the permit process worked towards convincing many actors of the safety of the facility. Moore thinks that it may be easier to find support in local communities than at state level because developing geological disposal facilities can bring jobs and economic growth to an area and they are often suggested for localities with long experience and involvement with nuclear facilities. This study complicates the recipe for success that

Eriksson and Dials distilled from WIPP, as it highlights the three levels of decision making involved: federal, state and local, all which have to act in support of a programme to make it work. The issue of the regulators and the regulatory framework appears even less straightforward if we also consider McCutcheon's (2002) detailed history describing how even as the DOE and New Mexico agreed on a formal role for the state in 1981, legal and regulatory measures on federal and state level could still be used to oppose the facility. In 1989 the energy secretary declared an indefinite delay until he and the non-DOE reviewers were satisfied with regard to the safety of the proposed facility. When this had been achieved in 1991 the New Mexico attorney general and a coalition, including the state of Texas and environmental groups, filed a lawsuit requiring that the DOE receive approval by the congress before waste shipments could begin. In 1996 further changes in legislation was passed by congress. The EPA issued a rule in 1997, certifying that WIPP complied with the standards, but the first shipments in 1999 were sent without the DOE and New Mexico having reached an agreement.

Further to the complicated political process McCutcheon (2002) describes how, when Carlsbad emerged as a potential site for geological disposal in the 1970s, scientists encountered unanticipated geological problems. Salt was a well-known material and the geology of the area well understood, however, the first test drillings in the area selected for the site showed that the underground salt beds leaned steeply, rather than gently incline, as had been the assumption. By changing the site criteria with respect to potential future exploration for oil or natural gas the facility could be moved to an area with more level salt beds. In addition, when drilling to greater depths the scientists hit brine, which contained hydrogen sulphide, a toxic gas, and methane, which is explosive. Scientists learned that brine pockets are common in this type of salt beds, they were not as dry as had been previously assumed. The brine became a political issue in 1987 when a university scientist suspected that brine was seeping into the waste disposal chamber and would pose a risk for dispersal of radioactivity in the environment. Brine continued to be an issue, in a 1998 report the Environmental Evaluation Group (EEG) discussed the topic under a number of sub headings, e.g. 'Brine Reservoirs', 'Brine production' and 'Brine seepage into salt shafts'. The EEG was certain that brine would be encountered at some point in the development of the repository because 'the WIPP-12 brine reservoir was large enough to most likely extend under the repository, a conclusion also confirmed by geophysical testing directly above the repository' (EEG, 1998: xix). However, some boreholes were dry while some were not, which made the EEG willing to accept a 60% chance of encountering brine in the construction of the repository. According to the EEG there was also evidence of brine seepage, with unexplained drying out, which was cause for concern (EEG, 1998: 202-203). DOE's technical and scientific reviews concluded that the seepage was not significant enough to pose problems, but the political negotiations arising from brine resulted in a scaling back of the amount of waste initially shipped, according to McCutcheon. The negotiations over the behaviour of the salt are interesting because they show how the challenges arising from surprises brought by the salt could be overcome through technical accommodation and political negotiation.

The challenges encountered in the construction of WIPP shows that it is possible to work out acceptable solutions to technical as well as social issues arising in the implementation of geological disposal. Faced with numerous socio-technical challenges the WIPP community (residents, local authorities, techno-science experts and implementer staff working together) championed the development and managed to overcome challenges posed by other socio-political actors as well as the geology. The process leading WIPP to its current fully operating status shows that universal agreement is not necessary, but with enough support of a local trans-disciplinary community and ability to negotiate on all levels it is possible to implement geological disposal in the USA.

6. Closing remarks

In light of the currently un-settled character of HLW/SNF geological disposal in the USA there is little point in offering firm conclusions, the situation may change at any time. The only thing that appears to remain stable is a general commitment to geological disposal as the long-term solution to the management of this hazardous waste. How this will be implemented and where the different elements of a programme will be located is currently undecided. As the long-running research and implementation programme for a repository at Yucca Mountain has been terminated, a new policy proposed and a bill put forward in the senate, it is possible that a brand new process will start in the near future. However, the termination of the Yucca Mountain programme has been challenged which means that the situation is open. It is possible that a new policy strategy is constructed to enable a re-launch of the Yucca Mountain programme.

At this point in time the main activity that can be undertaken in relation to US HLW/SNF geological disposal is discussion. To close we take a brief look at the public discussion as expressed in the first of two themed issues of *The Bridge,* a journal aiming to link engineering and society. The contributing authors come from NWTRB, university research, the BRC and the nuclear industry; the common theme is an acknowledgement of the importance of the social in the creation of safe long-term management of HLW/SNF. The opening article provides a broad outline of elements considered necessary for realising a repository, identifying trust between the actors involved as the most important feature (Metlay et al, 2012). In the next paper Carnesale (2012) summarises the BRC's proposal, drawing on experience of being a member he is optimistic with regard to the report providing a new beginning. A less optimistic view is offered by Kadak (2012) who focusses on what needs to be done in the near future, as reactor sites are closing down and SNF, in effect, becomes stranded. Rubenstone (2012) points to the challenges posed to the regulatory bodies in the face of a policy re-orientation away from the Yucca Mountain site, which has been the reference point for regulators since the 1980s. Addressing the issue from an industry perspective Fertel (2012) argues that SNF, in fact, has been safely stored by power plant operators since it first emerged, which the government needs to take into consideration when developing a new policy. The final paper in the issue discusses public attitudes to nuclear waste facilities and how they are influenced (Jenkins-Smith, et al, 2012). These articles show the complexity of the issue and bring out the fact that the adoption of BRC's proposal would not in itself solve the problems, only provide a framework within which a wide range of actors could operate.

To conclude this country report we can identify the socio-technical challenge facing geological disposal of HLW/SNF in the USA to be the adoption of a strategy, which will entail articulating a specific socio-technical combination that enables the safe disposal of this hazardous substance.

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