Making Distant Futures:
Implementing Geological Disposal of Nuclear Waste in the UK and Finland

Submitted by Marika Hietala to the University of Exeter
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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

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ABSTRACT

Making Distant Futures: Implementing Geological Disposal of Nuclear Waste in the UK and Finland

This thesis explores the making of distant futures through two nuclear waste disposal projects. Geological disposal of nuclear waste (GD) has enjoyed a technopolitical consensus for decades as the best available method for the long-term management of hazardous radioactive material, yet, to date, no geological repository facilities exist anywhere in the world. These ‘disposal facilities’ are expected to seclude nuclear waste from the environment for up to one million years, raising challenges for technical knowledge production, policy implementation and public expectations. Examining the proposed implementation of GD in the UK and Finland, this thesis focuses on the ways in which the management of nuclear waste is crafted in the present day and projected on, million of years into the future, as necessitated by the waste half-lives and as demanded by regulatory practice. In exploring these two national contexts, the thesis traces how knowledge is made about distant futures that exist beyond contemporary knowledge making capacity.

As a contribution to limited ethnographic discussion on nuclear waste matters, the making of distant nuclear futures is examined in spaces that have been overlooked in sociological literatures on GD e.g. materials science laboratories. The thesis draws from actor-network approaches, sociology of time and feminist STS literature to develop a ‘comparative-conversationalist’ framework. This approach enabled the comparison of wildly different cases by bringing them into conversation rather than direct comparison with each other. Based on participant-observations in two university research labs; interviews with civil servants, university researchers, technical consultants, regulators and industry representatives; and documentary analysis, I trace practices through which the future is *made safe,* and, nuclear wastes crafted as *manageable*.

The thesis will demonstrate how future making around nuclear waste varies over time and space. I propose that, because of the very distant future that GD concerns, we should discuss the safety aspects of GD and the ability of disposal facilities to contain wastes as ‘real unrealised present possibilities’. Towards this, I develop the notion of *contain-ability*. Contain-ability directs attention towards the relational makings of safety in the present, and the uncertainty of containment in the very distant future. It underlines safety as an emergent feature rather than an inherent property of disposal concepts and facilities achieved by engineers.

Overall then, the thesis demonstrates that a distant nuclear future is a crafted through situated makings that depend on available sociotechnical conditions, including: geological environments; the scale and complexity of nuclear industries and waste inventories; available financial resources and cultural reserves; and imaginations of wastes, nuclear futures and pasts. The successes and failures of policies for the implementation of GD cannot be construed simply through public acceptance or opposition arguments and more attention needs to be directed to the contingencies of scientific knowledge production and future making.

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ABBREVIATIONS

BEIS	Department for Business, Energy and Industrial Strategy (UK)
BERR	Department for Business Enterprise and Regulatory Reform (UK)
EBS	Engineered Barrier System
EA	Environment Agency
EC	European Commission
EU	European Union
DECC	Department of Energy and Climate Change (UK)
DIP	Decision-in-Principle
DTI	Department of Trade and Industry (UK)
GD	Geological disposal of nuclear waste
GDF	Geological disposal facility
HoC	House of Commons
HoL	House of Lords
IAEA	International Atomic Energy Agency
IGD-TP	Implementing Geological Disposal Technology Platform
IMechE	Institute of Mechanical Engineers
KBS-3	Nuclear fuel safety (Swe: *kärnbränslesäkerhet*) disposal concept
MEE	Ministry of Employment and Economic Affairs (Finland)
MOX	Mixed Oxide Fuel
MTI	Ministry of Trade and Industry (Finland)
NDA	Nuclear Decommissioning Authority
NEA	Nuclear Energy Agency
NGS	National Geological Screening
OECD	Organisation for Economic Co-operation and Development
ONR	Office of Nuclear Regulation
RWM	Radioactive Waste Management Limited
SEM	Scanning Electron Microscopy
SKB	Swedish Nuclear Fuel and Waste Management Company
SMR	Small Modular Reactor
STUK	Finnish Nuclear and Radiation Safety Authority
VTT	VTT Technical Research Centre of Finland
XRD	X-Ray Diffractometer

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1 FUTURE UNDERGROUND

> I mean, anyone can let Danger out but the really clever thing is finding somewhere for it to go afterwards.
>
> - Tove Jansson, *Sculptor's Daughter*

In this thesis, I will examine the implementation of geological disposal of nuclear waste (GD) in the UK and Finland. At the core of the thesis is a concern with the ways in which a multi-millennial future that stretches beyond knowledge is rendered predictable; how nuclear wastes are made manageable over the very long-term; and how GD is presented as safe through lab work, in policy and public documents.

Nuclear waste, like nuclear technologies, is tied to visions of planetary futures, even survival. For two consecutive years the Science and Security Board of the Bulletin of the Atomic Scientists have moved the minute hand of the Doomsday Clock forward by half a minute. The Doomsday Clock was founded by the Bulletin of the Atomic Scientists that in turn was founded by scientists from the University of Chicago who had been involved in the Manhattan Project. The Clock represents a fairly grim approach to the future. It draws on the imageries of apocalypse (midnight) and nuclear explosion (countdown to zero) to communicate threats to humanity and the planet. As things stand, contemporary society is two minutes from midnight. Each year a decision is made whether the minute hand of the Clock is moved or left in place. The decision to move the hand reflects a "broad and international view on existential threats to humanity, focusing on long-term threats" such as nuclear weapons proliferation and climate change (Bulletin Science and Security Board, 2017: 2). In January 2018 the Science and Security Board of the Bulletin published a press release alongside its decision to move the Clock forward. The Board wrote, "greatest risks last year arose in the nuclear realm […] To call the world nuclear situation dire is to understate the danger—and its immediacy" (Bulletin Science and Security Board, 2018: 2). The main reason for the nuclear threat, the Board argued, was the nuclear muscle flexing by North Korea and the USA during 2017. Additionally, the Board claimed that the insufficient response to climate change globally, but particularly in the USA, contributed to the decision to move the Clock forward.

Where in 2018 the Board did not mention nuclear power, in its 2017 press release the Board was more optimistic about the role of nuclear in mitigating climate change. The Board stated, “the energy potential of nuclear fission—and its capacity to reduce the greenhouse gas emissions that cause global warming—make nuclear power a tempting part of the solution to the climate change problem” (Bulletin Science and Security Board, 2017: 5). This is the view advocated by the nuclear industry (WNA, 2015) and the Finnish and UK governments (MEE, 2017; DECC, 2014a). However, in the 2017 press release the Bulletin’s Board also noted, “nuclear power has safety, cost, waste, and proliferation challenges”, and thus growth in the use of nuclear power “require[s] concomitant commitments to nuclear safety, security, and waste management that are politically, technically, and intergenerationally responsible” (Bulletin Science and Security Board, 2017: 5). In this thesis, I am interested in the nuclear waste challenge as a long-term threat and its management as form of future making. Nuclear waste ensures that the potential threat of nuclear technology and radiation do not go away even if societies gave nuclear power up today, since nuclear waste remains hazardously radioactive for multiple millennia.

The most hazardous types of waste (high level waste and spent nuclear fuel) stay radioactive from tens of thousands to a million years. ‘A million years’ is easy to write, but more difficult to really grasp. It challenges common sense conceptualisations of time as well as the capacity of the scientific knowledge production infrastructure to predict and know the future. Nuclear waste (first through military and then civilian applications) has been produced for more than 70 years, and it has already shaped the planet. A group of scientists has posited nuclear fallout, a type of waste, as the maker and marker of the Anthropocene, a geological epoch in which human society has become a geological force moulding Earth (Zalasiewicz et al., 2015). Based on chemostratigraphic data collected from Earth’s sediments, these scientists propose that the Anthropocene began with the Trinity bomb test in New Mexico in July 1945, while subsequent tests left an easily identifiable record to the sediments. In other words, nuclear “fallout – a waste – [has] become a signifying layer […] that defines our species’ legacy” (Hird, 2017: 188). Nuclear waste, Myra Hird writes, “constitutes perhaps the most abundant and enduring trace of the human; a major human-instantiated planetary de- and re-stratification” (ibid.). This only after seven decades of nuclear waste generation. What about the multi-millennial effect of this matter, if not managed in a safe manner?

Currently 50 countries are storing spent nuclear fuel in aboveground storage facilities. The global nuclear waste inventory holds approximately 270,000 tonnes of spent nuclear fuel (ANA, 2015; IAEA, 2003). 12,000 tonnes of waste is added to the inventory every year (ANA, 2015). Most nuclear waste globally is stored in cooling pools that rely on electricity to circulate and cool down water in the pools in order to prevent waste from overheating. As the radiation levels of nuclear waste naturally decay, the decay process produces significant amounts of heat. The loss of electricity and cooling can cause waste to overheat, catch fire and release radiation (Union of Concerned Scientists, 2013). Thus, contemporary storage arrangements are unsustainable, and potentially risky, in the long-term. Yet, *none of the most hazardous waste has been disposed of*, and nuclear nations have and continue to struggle with the implementation of disposal solutions.

Still, the global nuclear fleet is growing. 60 reactors are under construction in 15 countries, adding to the 450 operational reactors in 30 countries worldwide (NEI, 2017). Both the UK and Finland are currently constructing new reactors and foster dreams for more. Both countries are also in the process of implementing geological disposal (GD). The UK restarted its search for a disposal site in January 2018, while Finland, is the first, and currently the only, country in the world that has begun to construct its geological disposal facility (GDF), Onkalo, on the island of Olkiluoto in Western Finland.

In this context where nuclear technologies are framed perhaps increasingly as a threat; on one hand you have the concerns about non-proliferation and perhaps even nuclear altercation, and on the other the hazardous multi-millennial legacy of nuclear power generation, it is imperative to understand the role of GD in future making. How is GD imagined and what kind of a future is imagined through it to justify the construction of more reactors and the production of extremely hazardous waste? Especially, when contemporary nuclear societies have not been able to implement long-term solutions to deal with the existing, and continuously, growing nuclear waste inventory in the long-term. What kind of a vision of the future justifies leaving behind a radioactive legacy that continues to pose a threat 3,000 generations from now? Especially when the implementation of GD has proven out to be a major sociotechnical challenge.

1.1 Geological disposal of nuclear waste

The implementation of GD has proven out to be a major sociotechnical challenge of an international scale. GD has been conceptualised by the technoscientific community as a technical solution to a purely technical problem, while the lack of success in implementing GD has been attributed to ‘social factors’, such as public opposition and a lack of public acceptability (IAEA, 2007; OECD, 2000). Yet, finding ‘purely’ technical or ‘purely’ social factors in processes such as the implementation of GD is impossible. Rather, social scientific work on GD has argued that GD should be treated as a *sociotechnical challenge*. Anne Bergmans et al., describe sociotechnical challenges as situations in which “the relationship between the technical and social components is still unstable, ambiguous and controversial, and where negotiations are taking place in terms of problem definitions and preferred solutions” (Bergmans et al., 2012: 3). Since GD teeters on the limits of human knowledge and human knowledge production capacity, the futures imagined through GD remain contested. The ecological, political and economical stakes involved in the implementation of GD are high as GD deals with controversial issues; radiation; very distant futures, uncertainty, lack of control. How safety and the future are envisioned and made in the present are questions that link to the core concerns of this thesis.

GD, as a potential solution for the long-term management of nuclear wastes, is almost as old as the civilian nuclear industry. Where the first commercial reactor was connected to the grid in the UK in 1956, the US National Academy of Sciences (NAS) recognised GD as a suitable alternative for the long-term management of nuclear wastes already in 1957. A broad technopolitical consensus has formed around GD as the best available option for the long-term management of nuclear wastes. The Nuclear Energy Agency (NEA), for instance, has written

> The prevailing view of technical experts, as well as of many members of the general public […] familiar with the work relating to geological disposal, is that geological disposal is a safe and technically achievable solution. (NEA, 2008: 14)

Additionally, the 2011 Directive adopted by European Council states

> It is broadly accepted at the technical level that, at this time, deep geological disposal represents the safest and most sustainable option as the end point of the management of high-level waste and spent fuel considered as waste. (EC, 2011)

Although GD is presented in technical, institutional circles as a safe, permanent, and ‘publically acceptable’ solution to the long-term management of nuclear waste, no GDFs for the most hazardous nuclear waste exist. Experience with the Waste Isolation Pilot Plant (WIPP) for military waste, including plutonium, in New Mexico (USA) has already given some indications of the intricacies of managing nuclear waste and maintaining safety underground.

WIPP has been operational since 1999. In February 2014, an explosion within the underground facility led to plutonium and americium leaking out into the atmosphere (Alvarez, 2014). The explosion was caused by a switch from inorganic to organic cat litter that was used to absorb liquid waste. The US Department of Energy believes that a reaction between the organic cat litter and a waste drum caused the explosion, which led to the temporary closure of the facility that reopened in January 2017, nearly three years after the incident and a potential clean-up cost of $2 billion (Green, 2016). The WIPP case demonstrates complicated and situated makings of underground safety. GD involves the construction of an engineered facility specifically tailored to the waste that will be disposed of in the facility. Instead of a general recipe for safety, safety emerges through local sociotechnical encounters and makings.

In its simplest formulation, GD is the placement of nuclear waste in a facility that has been excavated deep enough into suitable bedrock so that the waste cannot travel back to the surface environment. GD, imagined as the ‘final disposal of ultimate waste by means of passive safety, as soon as possible’ (Schröder, 2017), is an anthropocentric vision of an essentially non-human future. Existing social science work in waste and discard studies argues that the notion of the ‘finality’ of disposal is not easily defendable (e.g. Hetherington, 2003; Hird, 2013). Waste, in particular something as long-lived as nuclear waste, resists disposal as the end point to its life (van Wyck, 2005). It will not just stop and sit quietly in the place designated to it by human society. Thus, the notion of the finality of GD is directed more at the human than nuclear waste. This idea of finality underscores the discrepancy between the longevity of radionuclides and the shortness of human lifespans.

The safety of GD is produced through absences. On one hand, the absence of waste from human society and on the other the absence of humans from the lifeworld of nuclear waste. As such, GD provides us with a textbook Actor-Network Theory (ANT) case study of delegation. Bruno Latour (1992) explains how we can either try to discipline people to do what we want them to do or alternatively we can entrust and delegate that task to nonhumans, such as the GDF. The making of safety and safe futures through GD relies on a multi-barrier system (see Figure 1), and a notion of passive safety – that is the absence of human intervention in the operation of the GDF. Multi-barrier concepts include an Engineered Barrier System (EBS) that will work together with the geological barrier to prevent the migration of waste to surface environment.

While the making of a safe future through GD depends on absence, it also relies on alliances between organic and inorganic, human and nonhuman beings. Thus, delegating safety to the GDF, does not automatically translate into safety in practice. Delegation does not mean control, but is contingent on the delegator and the delegated playing their agreed roles (Schröder, 2016); the GDF to keep waste absent from the aboveground, and humans to remain absent from the underground. Therefore, if safety is a contract between humans and nonhumans to carry out their roles, it is necessary to be curious about “our living-space entanglements” (Tsing, 2016: 6), that is, how safety is made and negotiated through situated and relational sociotechnical doings.

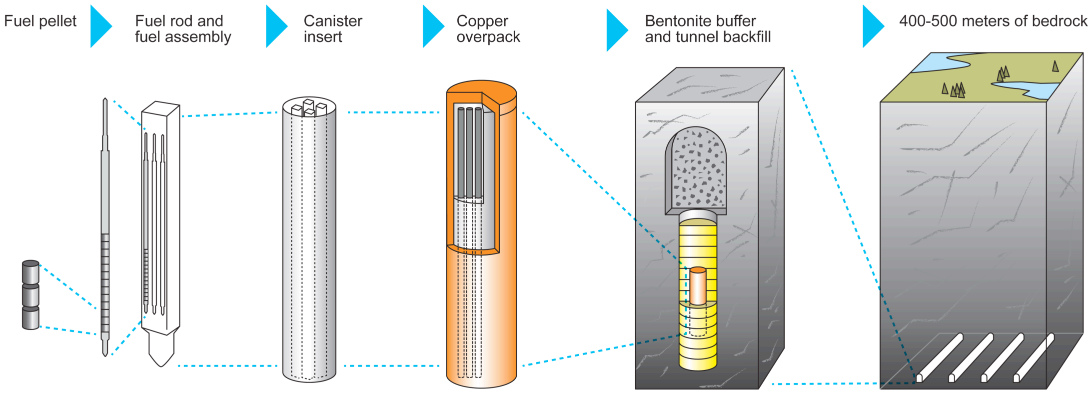

Figure 1. KBS-3 Multi-barrier concept being implemented in Finland and Sweden. Courtesy of Posiva Oy.

The safety and implementability of GD are negotiated in relation and in contrast to other nuclear waste management alternatives. The UK's Radioactive Waste Management Limited (RWM), charged with the implementation of GD in the UK for instance describes GD as "less vulnerable than surface storage to natural processes such as climate change" (RWM, 2018). It also considers GD as 'technically achievable', environmentally safe (unlike disposal in polar ice sheets or the seabed) and safe to implement (unlike firing nuclear waste into space). The case for the safety of GD is thus made through relational doings, a matter I will explore in Chapter 5.

GD in the UK and Finland

In this thesis, I explore the implementation of GD in the UK and Finland. The UK and Finnish GD projects provide us with interesting and contrasting case studies. Where the UK GD project has been characterised by ruptures and discontinuities, Finland is close to becoming the first country in the world to begin the disposal of nuclear waste. How the trajectories of the UK and Finnish GD projects have become as different as they are is an overarching concern of this thesis. In both countries work towards a long-term solution for the management of nuclear wastes begun in the latter half of the 1970s when the first reports on nuclear waste management were published in the UK and Finland.

Since then GD has transformed into one of the more enduring technoscientific controversies in the UK (Bickerstaff, 2012; Gregson, 2012). The history of the UK GD project has been discussed in detail elsewhere (e.g. CoRWM, 2006), and I will not delve too deeply into that here. The framework for the latest iteration of the UK's disposal project was laid out in the 2014 *Implementing Geological Disposal* White Paper published by the Department of Energy and Climate Change (DECC, 2014). The White Paper followed the termination of the previous siting process in West Cumbria in January 2013, when the Cumbrian County Council decided to withdraw from the process. The White Paper reaffirms the Government's commitment to GD as the UK's chosen long-term waste management method, and to a voluntarist siting process as recommended by the Committee of Radioactive Waste Management (CoRWM) in 2006. Following a public consultation on lessons to be learned from the Cumbrian experiences, the 2014 White Paper maps the process going forward, over a series of time scales. The first two years of the process, following the publication of the White Paper, were designated to conducting a National Geological Screening (NGS) for compiling existing geological data, developing land-use planning processes and preparing to work with local communities. The following 15-20 years are to be spent engaging with local communities, investigating potential disposal sites and designing the GDF. From then on, 100+ years have been allocated to the construction, operation and closure of the GDF (see Figure 2). Consultations on the siting and community engagement processes commenced in January 2018, two years behind the original schedule. It is already clear that the White Paper implementation process is delayed and the future progress of the UK GD is accruing uncertainties.

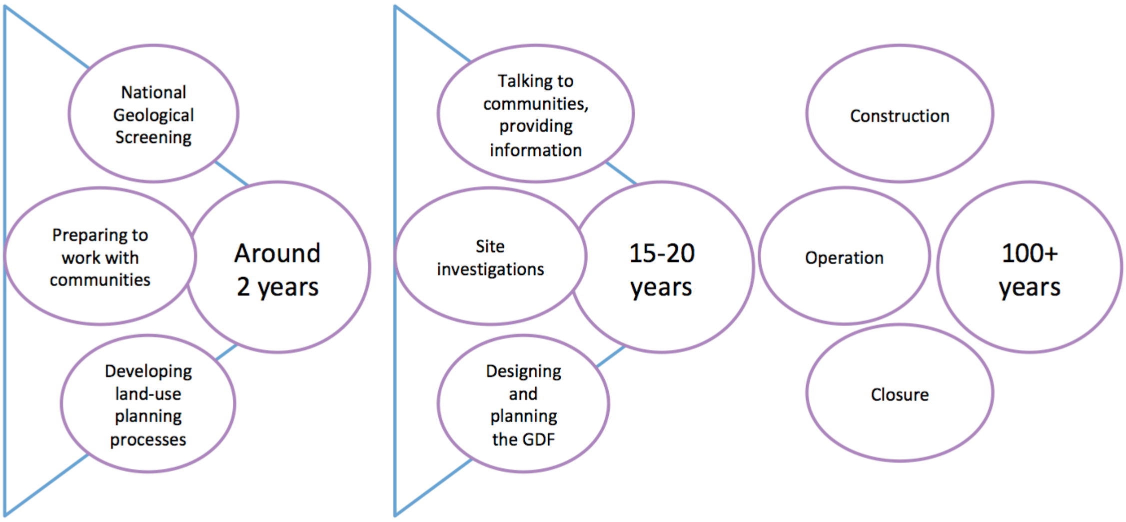

Figure 2. Timeline of the UK GD project. Adapted from DECC (2014a).

In Finland, Posiva, the nuclear waste management organisation, is preparing to submit an operational licence application for the GDF. Known as Onkalo, this future GDF is in the municipality of Eurajoki that also hosts the Olkiluoto power plant. Eurajoki was chosen as the disposal site in 2001 after the parliament ratified the Decision-in-Principle (DiP), made by the Finnish State Council, that GD aligns with the 'overall good of society'. The initial construction of Onkalo as an underground research lab and rock characterisation facility began on the island of Olkiluoto in 2004 and was completed in 2014. In 2015, the Finnish parliament granted Posiva a construction licence for the actual GDF – a tunnel network extended from Onkalo. As part of the operational licence application, Posiva will conduct a full-scale test (FISST) in Onkalo at the depth of 420 metres during 2018. The aim of FISST is to demonstrate that the barriers of the EBS work together to provide passive safety as envisioned. The test is intended to support the full operational test planned for 2023 and actual disposal activities that are envisioned to commence in the mid-2020s. The closure of the GDF is planned for around the 2120s.

1.2 Beyond certainty, beyond the human

In his book *Deep Future,* Stephen Baxter (2001) claims that for the first time in history human societies are attempting to chart the future of humanity for the next million or billion years. Often, these attempts to chart the future take humanity into space. In a 2016 interview, Stephen Hawking, for instance, argued he did not "think we will survive another 1,000 years without escaping our fragile planet" (in Boult, 2016). To secure humanity's existence, Hawking urged us to "look up to the stars and not down at our feet" for our future (ibid.). Hawking later revised the timeframe he envisioned humanity has left on Earth. Instead of a millennium, he posited we have a century to pack our bags to flee our planet. Only 100 years. Hawking's vision for the future of humanity included a "base on the Moon by 2020 and a manned landing on Mars by 2025" (Hawking, 2017). These ventures are desperately needed, he argued, in order to ensure our continuation as a species. "If humanity is to continue for another million years", Hawking contended, "our future lies in boldly going where no one else has gone before" (ibid.). Hawking's vision entails journeying beyond certainty, beyond current knowledge. It asks humanity to be generous towards uncertainty, by positioning the uncertainty of survival in space against the certainty of demise on Earth. According to Hawking humanity must embrace uncertainty and build a future in spaces beyond knowledge, in spaces of uncertainty.

Although located in a completely *different* space, GD, too, can be read as an attempt to chart the future. As with Hawking's vision of the future, the epistemological challenge with GD is that GD expands and exists in a future beyond knowledge. Because of the excessively long timescale that GDFs need to operate, GD as a technology is uncertain. There will be unanswered questions about the workability of the technology to which answers will not be forthcoming for multiple millennia (Bergmans, Landström and Schröder, 2014). The one million years into the future that GD projects seek to chart provides a major challenge for the implementation of GD, perhaps an even greater than the challenge posed by radioactivity.

Thus, in this thesis when I talk about GD, I talk about precarious future making deep into times that deflect certainty and knowability. Any discussion of GD inevitably has to confront timescales that are of the geological kind. Nuclear materials - the matter to be held in a GDF - decay so slowly that they have been used to calculate the age of Earth. Bertram Boltwood was the first scientist to use the decay rate of Uranium to calculate the age of Earth. Nuclear power technology relies on that same, slowly decaying Uranium to fuel its reactors. Thus, "the very nature of nuclear technology, with the necessity to mine and refine naturally radioactive ores and minerals" means that through nuclear technologies, societies "engage with a timescale beyond human understanding" (Wilson, 2012: 224). The GDF is envisioned, by technical experts and governments alike, to contain nuclear waste for long enough to allow the waste to decay to a level that has been deemed safe. This means that safety is envisioned up to *one million years*.

As far as this thesis is concerned, when Henry Gee asserts, "it's about change, not stasis; about process, not pattern; about tales, not tableaux; about becoming, not being" (Gee, 2000: 134) he might be talking about GD. While he, in fact, describes the evolution of species, this description is equally apt as a characterisation of the future of GD. The GDF is a hybrid entity composed of engineered and geological barriers. Sustained multi-millennial interactions between wastes, microbes, groundwater, bedrock and the EBS ensure that the GDF is always becoming, always evolving. Mapping that evolution in the present is a challenge. Extrapolating results from short-term laboratory experiments into the real-life conditions is difficult, and even more so when we are talking about the very distant future (van Poel, 2011). The developments and evolution of the GDF take place beyond human senses. The placement of waste underground prevents the detection of possible leaks in the future. The inability to accurately know the future together with the extremely slow process of radioactive decay ensure that the implementing generations cannot know whether GD as the chosen option for the long-term management of nuclear wastes works in the future as envisioned in the present. Nuclear waste transcends time and space. It is what Tim Morton calls a “hyperobject” (Morton, 2013: 1). Hyperobjects, such as nuclear waste, “involve profoundly different temporalities than the human-scale we are used to. […] Hyperobjects occupy a high-dimensional phase space that results in their being invisible to humans for stretches of time” (ibid.). Waste will move and the GDF evolve over the millennia it is expected to operate. While, GD, in its essence, is about slowing down or halting movement, it is also an attempt to isolate and contain stuff that resists containment (van Wyck, 2005). GD is about trying to control stuff that has for decades controlled our imaginations.

Thus, when I talk about making futures through GD, I talk about the need to develop sensitivities to futures we will not know. Weighing the Finnish case, Abraham van Luik of the US Department of Energy (DoE) notes how the Finnish regulations for GD “cover the entire future span, out to the very long time period – but they also say that, once the ice has built up again and covered Finland, it won’t be Finland. No one will live there. But it doesn’t matter whether anyone lives there or not: you still have to provide a system that’s safe for whoever’s going to be there when the ice retreats” (in Manaugh and Twilley, 2012: 237). Thus, when we talk about GD, we talk about the need to develop a flat ontology and move away from human exceptionalism. So, I propose that if contemporary societies are to make liveable, safe, futures such as envisioned by GD projects, there is a need to step away from the divisions between human and nonhuman, underground and aboveground, present and future. Instead of privileging one side of these dichotomies, they need to be treated symmetrically. To make liveable, safe, futures, it is necessary to understand or seek to understand how our futures and situated doings entangle and might affect the futures of multiple others, including those with whom we share the planet in the short-term, and those who might outlive us.

1.3 Summary of the thesis and individual chapters

The thesis is divided into seven chapters. In Chapter 2 I review the main literature that is pertinent to the thesis arguments. I will highlight the need to begin with endings when we talk about the implementation of GD projects; the distant future as the end to certainty; GD itself as an end point to the travel of nuclear materials, and the Nuclear Age as End Time (Anders, 1962). Drawing on existing work, I will discuss wastes as ambiguous matter and GD as a ‘sociotechnical experiment’, thus questioning the notion of GD as a permanent solution to the long-term management of nuclear wastes. Thereafter, I review relevant literature on ‘future making’ with particular focus on the uncertainties and ethics around future making.

In Chapter 3 I discuss the methods I used in my fieldwork and highlight some of the key experiences of doing fieldwork through the notions of absent presence and present absence. Taking a cue from Natasha Myers (2008, 2012), I discuss participant-observation as *body-work*, as a tool of ethnographic sense-making, giving access to new forms of knowing and new ways of following actors (Latour, 1987). Second, I discuss my take on diffraction (e.g. Haraway, 1996) as a methodological tool to explore the implementation of GD in a comparative setting, and introduce the notion of *disposal cultures*. Disposal cultures are situated compositions and composers of particular forms of knowledge and knowing. Disposal cultures have no explanatory power, but have an inbuilt diffractionist sensitivity. Diffraction is a relativist take on the world that explores the ways in which reality and differences are relational and emerge from specific, situated intra-actions between heterogeneous actors. The diffractive approach enables a conversation instead of comparison between the UK and

Finland and avoids the trap of simplistic like-to-like comparison. Finally, I discuss some of the technicalities of the interview, writing and analysis processes.

Chapter 4 is concerned with the UK and Finland's nuclear pasts and futures. I begin with a description of the present nuclear infrastructures in the UK and Finland as a way of laying ground for the following chapters. In the mid-part of the chapter, I explore the making of the waste challenge; how industry and policy descriptions of nuclear waste have moved between problematisation and deproblematisation of waste matters in the UK and Finland. In the final part of the chapter, I change pace and focus on the UK's relationship with nuclear. Here, drawing on Latour's Frankensteinian technologies (Latour, 2004) and Puig de la Bellacasa's matters of care (Puig de la Bellacasa, 2011, 2017), I engage in speculative thinking about the nuclear waste challenge as a result of 'our' infatuation with nuclear things. Focusing in particular on the UK's case, I propose that the nuclear waste challenge has emerged from our love, rather than fear, of nuclear technologies.

In Chapter 5 I explore the making of the deep future and the making of safety through relational doings. I explore how the aboveground and certain geological conditions are used to render the deep future of GD scientifically predictable. I examine, in particular, how geological faults, fractures and cracks are envisioned simultaneously as *spaces of risk* and as *spaces of predictability*. How these spaces are subsequently utilised in making the technical case for safety and predictability of GD are also presented in making a case underground safety. I then turn my attention to the engineering concepts and design of the GDF and propose that in its adversity to innovation, the historicity of its materials and its aim to slow down time and movement, GD can be conceptualised as a *technology of stagnation*. In the final part of the chapter, I explore some of the ways in which the deep future is made on the lab bench; what kind of everyday scientific work brings the future into the present?; and what kind of work is required to make predictions of the deep future in the present? The central argument here is that the making of safe, deep futures relies on situated relational makings and simplifications of the complexity of the disposal system.

Chapter 6 draws on the idea of GD as an on-going sociotechnical experiment (Bergmans and Schröder, 2012). Here, I propose that the ways in which the UK and Finnish disposal cultures relate to the future, and the idea of finality, affects the processes of implementation of GD. In the first instance, I examine how the future of GD is imagined through radionuclide half-lives and project timetables. I propose that the envisioned distance to the GD future (Michael, 2000), how imminent that future is, has shaped the implementation UK and Finnish GD projects. Next, I trace the indeterminacy of nuclear wastes. Here, I focus on plutonium, reprocessing technologies and the notion of retrivability of nuclear wastes. I discuss how the boundaries between wastes and assets, and between disposal and storage are not as clear-cut as official descriptions of GD let us understand. I also consider how ambiguity in these definitions and descriptions might affect the implementation of GD.

In the ultimate chapter of this thesis, I synthesise the main points from the earlier chapters and summarise the answers to my research questions. I present the concept of *contain-ability* for exploring GD as a form of future making. Contain-ability is, I will argue, ‘a real unrealised present possibility’ (Bell and Olick, 1989) of GD. It is a contingent and situated *making*, taking place, for instance, on the lab bench, through policy decisions, public documents and other representations of disposals and wastes. How contain-ability is made depends on the imaginations of nuclear/GD futures (chapter 4); available geological conditions and materials envisioned as containers and barriers (chapter 5); and the stuff that needs to be contained (chapter 6). I also argue that contain-ability varies over time and space. It is not something inherent or present in GD projects or different disposal concepts, but only emerges through *relational sociotechnical doings*.

By highlighting the contingencies of future and safety making through GD, this thesis has a policy implication. Where GD projects still tend to be mostly driven by technocractic logics, this thesis highlights the negotiability and relational aspects of making wastes, safety and the future. Throughout this thesis, I underline the entanglement of the social and the technical in the implementation of GD, and the making of the future through GD as sociotechnical, rather than a purely technical, challenge.

2 BEGINNING WITH ENDINGS

> The Hitchhiker's Guide to the Galaxy skips lightly over this tangle of academic abstraction, pausing only to note that the term "Future Perfect" has been abandoned since it was discovered not to be.
>
> - Douglas Adams, *The Restaurant at the End of the Universe*

This chapter is all about endings. By exploring endings, I introduce concepts and literatures that are important for this thesis. I begin to map out the necessity of a flat ontology (Latour, 2005) for understanding the processes through which both the future and the safety of GD is made and presented by GD projects. In the first section of the chapter (2.1) I explore Günther Anders' idea of the present, the Nuclear Age, as the End Time. The section begins to trace the long-term effects of nuclear activities and how these configure our relationship with the future and nonhuman beings. In doing so, I draw on the concept of care as an integral part of technoscientific practices, and, therefore, of future making. In section 2.2 I critique the multiple representations of GD as an 'end point' or a 'permanent solution' to nuclear waste management. Drawing on existing social scientific work on waste and GD, I develop the existing idea that GD should be treated as a long-term sociotechnical experiment. I posit that because of the discrepancy between the lifespans of nuclear waste and the existing ability to engineer containment in the long term, GD is a temporal rather than a permanent category.

The next two sections focus on the ontological challenges imposed by nuclear waste and the deep future of GD. Section 2.3 approaches the future as the *end of certainty*. I discuss the discrepancy between our abilities to make and know futures and cover key concepts that have emerged from the 'futures' literature. Finally, in this section I position the 'deep future' as a sociological research object. The penultimate section of the chapter draws on the work of Tim Morton and Donna Haraway to argue for a need to reconfigure common readings and divisions of the world in ways that no longer privilege the human or the present in order to make safe and fair futures. The final section of the chapter presents the research questions that guided the making of this thesis.

2.1 End Time as liveable condition

In *Future Matters* Barbara Adam and Chris Groves (2007) argue that nuclear technology is a textbook example of contemporary society's 'Promethean power' to create futures. What they mean is that contemporary capacity to construct and create futures through nuclear surpasses existing capability to know and take responsibility for the futures made through nuclear technology. The effects of civilian nuclear power – that is nuclear waste – are of interest in this thesis. Before moving on to waste matters, it is worth noting, however, how the promise of nuclear as a vessel for 'better futures' has shifted and decayed.

Nuclear power has offered promises of shoring up resource and energy gaps with 'electricity too cheap to meter', it has promised national prestige (Hecht, 2009) and progress (Jasanoff and Kim, 2009). The promise of cheap electricity of the early Nuclear Age has decayed into experiences and imageries of nuclear accidents. Where nuclear has, at least in part, failed to deliver these promises, it has produced an international, intergenerational, interspecies threat. Nuclear weapons proliferation, and the recently resurfaced concerns about weapons are the obvious example of this, and nuclear weapons have received some social scientific attention (e.g. Burke, 2016; MacKenzie, 2012). Yet, even if we look past nuclear accidents and the past and potential future destruction sown by the bomb, nuclear technology has produced, perhaps unintended, but definitely long lasting effects deep into the future. The promise of nuclear has been replaced with concerns over nuclear wastes and their long-term management.

Waste, as the product of nuclear technology, challenges our understandings of safety and our relationship with the future. Waste remains hazardous for multiple millennia, thus undermining the safety of the living world if left unattended. Writing at the height of the Cold War in 1962, Günther Anders argued that with nuclear technology we have reached the *End Time*. For Anders the End Time is characterised by the nuclear (weapons) threat as a world condition. Living under the constant threat of our own (nuclear) power "to transform any given place on our planet, and even our planet itself, into a Hiroshima" means that the Nuclear Age is ""the Last Age": for there is no possibility that its "differentia specifica," the possibility of our self-extinction, can ever end – but by the end itself” (Anders, 1962: 493). The Nuclear Age as the Last Age is the End Time. For Anders, the Nuclear Age is the time before the end. The End Time is the time preceding nuclear apocalypse, the end of time itself. In the End Time, Anders argues, the basic moral question of “How should we live?” needs to be radically rephrased as “Will we live?”. Surviving and living in the world in the End Time is no longer self-evident. The future is no longer a matter of fact. It is something that can be lost. In the End Time, the future becomes a matter of care (Puig de la Bellacasa, 2017). Surviving and living in the End Time require active doing and intervention to prevent the End Time from becoming the end of time. “We must”, Anders argues, “do everything in our power to make the End Time endless” (Anders, 1962: 494). In other words, the End Time is a liveable condition that needs to be cared for and maintained to avoid the coming of the end of time. For Anders, public demonstrations and marches are a way of intervening in the world to maintain its liveability; and a way of demonstrating care for the world to prevent its destruction and the arrival of the end of time.

In a less dramatic way than nuclear weapons, nuclear waste underlines the Nuclear Age as the End Time. While the sheer multi-millennial lifespan of nuclear waste and radionuclides, as we will see further below, ensures that humanity will live and die in the Nuclear Age, taking care of nuclear waste, containing its movement now and in the future can be read as an attempt to make the End Time endless in the way Anders envisions.

The End Time, then, does not signal the end of the time. Rather, it signifies the fragility of the future and the ever-present possibility of its ruination. The End Time has the potential of becoming the end of time through nuclear apocalypse, a serious nuclear accident or the slow poisoning of the living world by highly radioactive waste. Bill Gilbert suggests that we need a new “narrative as a […] species”, a narrative that “encompasses the expanse of planetary time, not the fleeting moment of pop culture” (Gilbert, 2012: 53). He posits, that we need this new narrative if we want “to extend [the Anthropocene] thousands of years into the future” (ibid.). Anthropocene is the label given to the current geological epoch in which human activities “have become so pervasive and profound that they rival the great forces of Nature and are pushing the Earth into planetary *terra incognita*” (Steffen, Crutzen and McNeill, 2007: 614). While the

Anthropocene and the Nuclear Age are not synonyms, both natural and social scientists have proposed that the beginning of the Nuclear Age marked the beginning of the Anthropocene (e.g. Morton, 2013; Zalasiewicz et al., 2015). In 2015 a group of scientists traced the start date of the Anthropocene to

> the world's first nuclear bomb explosion, on July 16th 1945 at Alamogordo, New Mexico; additional bombs were detonated at the average rate of one every 9.6 days until 1988 with attendant worldwide fallout easily identifiable in the chemostratigraphic record. (Zalasiewicz et al., 2015: 196)

The Trinity test in New Mexico, the subsequent nuclear weapons tests and the resulting nuclear fallout have been posited as the markers and makers of Anthropocene. “Waste”, nuclear or otherwise, Myra Hird writes, “has become *the* signifier of the Anthropocene” (Hird, 2015). The consequences of the Anthropocene, like those of the Nuclear Age, extend into the very distant future. Donna Haraway posits that the Anthropocene “marks severe discontinuities; what comes after will not be like what came before” (Haraway, 2016: 100). For Haraway, the Anthropocene is a wrinkle in time. It marks discontinuity and change. In a sense, her reading of the Anthropocene, then, is similar to Anders’ conceptualisation of the End Time. Yet, where for Anders the End Time is followed by the end of time, Haraway holds that “our job is to make the Anthropocene as short/thin as possible and to cultivate with each other in every way imaginable epochs to come” (ibid.). Thus Haraway’s reading of the future is more optimistic than that of Anders. Where Haraway wants change and to bring about a new epoch, Anders’ focus is on maintaining the status quo; prolonging the present, the End Time, for as long as possible, for after that there is nothing. Thus, while both Haraway and Anders advocate active doing to maintain a liveable world, their visions of the future are at odds with each other. Anders’ gloom is balanced by Haraway’s hopefulness of better times yet to come.

Reflecting on Gilbert’s words (see the bottom of page 33), Jane Bennett notes that we, as humans, “unconsciously project forward, if not the destructive, short-sighted version of the Anthropocene, [then] a “cene” that includes, *for as long as possible*, the presence of the anthropos” (Bennett, 2012: 245, my emphasis).

Echoing Anders' call to care for the End Time (so that it does not morph into the end of time), Bennett posits that in the Anthropocene, we "seek the postponement of the arrival of a radically posthuman future" (ibid.: 246). To postpone a posthuman future and to prevent the becoming of the end of time, contemporary societies need to unearth "possibilities for humans to evolve ways to live in relation to geologic time" (Ellsworth and Kruse, 2012: 14). In order to make liveable futures common conceptualisations of time need to be expanded. This, I posit, is in a sense what GD projects seek to do. They seek to intervene in the world, to prolong the End Time by constructing protective structures that have geological, rather than human, lifespans. GD seeks to engineer structures that can meet, if not match, the extremely long lifespan of nuclear waste. GD is a technology that seeks to isolate nuclear waste underground for as long as possible; to protect the anthropos, but also the flora and the fauna. In this thesis, I trace some of the ways in which the UK and Finnish GD projects seek to intervene in the world to protect it. To intervene in the world in order to protect it in the long-term requires that GD projects approach the future as a matter of care (Puig de la Bellacasa, 2011; 2017).

Matters of care

Puig de la Bellacasa (2011, 2017) has taken the notion of matters of concern (Latour, 2004) to develop the notion of matters of care. Concern and care as affective states, Puig de la Bellacasa posits, are related. They both bring back to focus the multiplicity and messiness of (scientific) work that the black boxed matters of fact hide. Where concern denotes worry and trouble, care adds *a sense of commitment*. It has stronger affective and ethical connotations. It does not replace concern at the core of the politics of things, but brings in something else into the mix. Crucially, "the quality of "care" [can] be more easily turned into a verb: to care. One can make oneself concerned, but "to care" contains a notion of doing that concern lacks" (Puig de la Bellacasa, 2017: 42). As such, care "involves affective, ethical and hands-on agencies of […] material consequences" (ibid.: 3). Care "implicates different relationalities, issues, and practices in different settings" (Puig de la Bellacasa, 2017: 3); care is always situated. Thus, for instance, the EU's concern for nuclear wastes translates to different care and nuclear waste management practices at the level of Member States that are responsible for the nuclear wastes they have produced. EU

Member States consequently have developed ways to care for their waste through a range of disposal concepts and approaches to GD that reflect their particular sociotechnical conditions. In this sense we can see care – taking care of nuclear waste – as a situated practice emergent of local sociotechnical realities (Mol, 2008). GD does not demand or offer a singular solution to the long-term management of nuclear waste. Rather, the range of disposal concepts and futures envisioned by EU Member States underlines the multiple ways in which European nuclear nations are, or are planning to, take care of their nuclear waste.

To care "is to affect and be affected by the thing at stake within a controversy or debate" (Michael, 2017: 131). Care engages practitioners in their worlds; care is an *active practice* (Martin, Myers and Viseu, 2015). It requires *"a willingness to respond"* (ibid.: 11, emphasis in the original). Before we care for a thing, we "must have the capacity or willingness to respond, to be called into action, to be hailed by that object or phenomenon. In short, a person who cares must first be willing and available *to be moved by* this other" (ibid.). Vinciane Despret reminds us that care is not superfluous but an attempt to become interested in an issue; it is not just the "*result* of scientific theoretical understanding, it is the *condition* of this understanding" (Despret, 2004: 132, emphasis in the original). Care, thus, can be located at the heart of scientific knowledge production, and forms of future makings, such as GD. Caring is intimately entangled with knowledge production, while "de-passioning" science and research "does not give us a more objective world, it just gives a world 'without us'" (Despret, 2004: 132). Caring, then, cannot be separated from knowing. Carrie Friese (2013) has observed that caring can be taken to signify good lab science, while others have conceptualised care as an "inevitable part of scientific research", even if it still "requires constant negotiation and tinkering in order to be accommodated by the systems with which it lies in uneasy relationship" (Giraud and Hollin, 2016: 17).

In this sense, caring can be understood as a 'disruptive doing', and as an ethical and a political intervention (Puig de la Bellacasa, 2017). Puig de la Bellacasa draws on the definition of care as "everything that we do to maintain, continue and repair "our world" so that we can live in it as well as possible. That world includes our bodies, ourselves, and our environment, all that we seek to interweave in a complex, life sustaining web" (Tronto, 1993: 103). Following this definition, GD can be conceptualised through care as an active attempt to maintain and continue the world, to extend the End Time. Practices of care, treating, managing, and disposing of nuclear waste, are at the heart of safe futures envisioned through GD. Protection of both humans and nuclear (that is; care for humans and nuclear) lie at the core of GD safety imaginaries, as we will see in Chapter 5. Through care, GD projects seek to maintain a livable world.

Yet, GD, as care and a world-sustaining doing is a non-innocent practice. Haraway has argued that the point of care "is to make a difference in the world, to cast our lot for some ways of life and not others. To do that, one must be in action, be finite and dirty, not transcendent and clean" (Haraway, 1997: 36). In other words, priorities need to be set and sides chosen. GD, as safety making and care-ful doing, thus, relies on prioritising certain spaces and materials and ignoring others. In line with Haraway, Aryn Martin, Natasha Myers and Anna Viseu write

> Care is a selective mode of attention: it circumscribes and cherishes some things, lives, or phenomena as its objects. In the process, it excludes others. Practices of care are always shot through with asymmetrical power relations: who has the power to care? Who has the power to define what counts as care and how it should be administered? […] Care organizes, classifies, and disciplines bodies. (Martin, Myers and Viseu, 2015: 3)

Care is a selective mode of attention and active doing, invites us to ask "For whom we care?"; "Who cares?"; "What for?"; "Why do 'we' care?"; and "How to care?" (Puig de la Bellacasa, 2011: 96). By understanding care as selective and situated doing that is governed by our willingness to respond, we can begin to see how caring for a thing can shift our ontological conceptions of time and relationships with others (Schrader, 2015). As a transformative ethos, care has ontological significance with cultural, ethical, political, material and social impacts. It shapes, reconfigures and reorders the world. Drawing from this what I aim to do in this thesis is to illuminate how the nuclear waste problem has been made and remade through degrees of care and negligence of nuclear things. I will engage with the notion of care as a selective mode in Chapter 4, as a way of speculating about the making and becoming of the waste problem in the UK by exploring how the changing attention to nuclear materials has affected nuclear waste ontologies. In Chapter 5, I will trace how care for the future through GD means that safety is made and argued for by prioritising certain spaces and sociomaterial configurations over others.

As we will see in section 2.3, the ways in which we conceptualise time and the future shape how we care, how we begin to care, and how we envision responsibility. To live on a 'damaged planet' (Tsing, 2016) requires that we not only extend care and concern temporally to generations ahead, but that we commit to living and dying 'response-ably' in unexpected company (ibid.). The "joint fortune that all forms of life share with human technoscience is no longer news" (Puig de la Bellacasa, 2011: 85), and future making through GD needs not only consider multiple human generations, but also a multitude of nonhumans. Caring for the future, ensuring a future in the End Time requires intergenerational and more-than-human sensitivities. Haraway argues, "what used to be called nature has erupted into ordinary human affairs, and vice versa, in such a way and with such permanence as to change fundamentally means and prospects for going on" (Haraway, 2016: 40). Hird (2013a) similarly has argued that to live in the world and to foster more-than-human sensitivities, we must begin to relate to and care about the future in geoscientific terms. What this means is the adoption of a long-term approach to future making that requires an acknowledgement that in deep time, humans occupy just "one moment in the wider life of a thing" (Parsons, 2008: 392).

Living in the End Time

Understanding the future in geoscientific terms foregrounds times before and after humans, and enables a sensitivity to trace how the world is made through nonhuman encounters and interactions. "Humans", Puig de la Bellacasa notes, "are *in* relations of mutual care" (Puig de la Bellacasa, 2010: 164). Humans are not alone in caring for Earth and its beings. The making of safe futures through GD relies, to a great extent, on nonhuman encounters and interactions (and on understanding and predicting these encounters). The GDF is expected to contain the highly radioactive waste and to provide safety from “hundreds of thousands to more than a million years”, that is, for “periods of time beyond normal human comprehension” (Alexander, Reijonen and McKinley, 2015: 75-76). The timeframe of GD is vast, and the making of futures through GD demands that we engage with times we do not necessarily understand and will not know. Nuclear waste and the radioactive threat they pose on the living world will outlive humans, as will the GDF – if the models, calculations and predictions that have and are being made about the future of the GDF are correct. Because of this, the long-term management (or care) of nuclear waste has been delegated to nonhuman actors, and the international nuclear waste community conceptualises long-term safety through the absence of human actors (see section 2.2 below). In Chapter 5, I conceptualise GD as a technology of the End Time, as a *technology of stagnation*. As the long lifespan of nuclear waste poses a threat to life aboveground, GD seeks to make safe futures and to maintain a liveable world by slowing down time and by separating nuclear waste and humans through the disposal of waste underground. Thus, where Anders understands the End Time through the human and human concerns for survival, I suggest that to make liveable futures we have to let go of anthropocentric approaches to what it means to live in the End Time. Taking care of nuclear waste, as a means of making liveable futures in the End Time, demands interspecies, geoscientific and multigenerational sensitivities to time (I return to the need for a flat ontology in understanding future making through GD in section 2.4).

2.2 GD as the end point

The European Commission describes GD as “the end point of the management of [nuclear] waste” (EC, 2011). In the UK, the Department of Energy and Climate Change (DECC), in the 2014 White Paper *Implementing Geological Disposal*, defined GD as a “permanent solution” to the long-term management of nuclear waste (DECC, 2014a: 5). Conversely, in Finland the term ‘final disposal’ (*loppusijoitus*) is preferred over that of ‘geological disposal’ (e.g. Posiva, 2012). ‘Final disposal’ as a term explicitly suggests finality, an end or an ending. In doing so, it seems to simplify GD by invisiblisising uncertainties and taming nuclear waste. In the first instance, ‘final disposal’ directs attention away from the geological realm, away from fractures, cracks, scientific uncertainties and knowledge gaps. The term ‘final disposal’ guides the reader’s focus towards engineering, away from the natural and the geological. It guides attention to that which is manageable and controllable. It guides attention away from the *deep future* (see further below), the long timeframe of GD and the difficulty of ‘finding somewhere’ for the waste to go. Finally, the notion of ‘final disposal’ proposes an end point for nuclear waste. The ‘final’ in final disposal can thus be read as an end to movement, threat and risk. Final disposal proposes passivity and permanence.

The ‘finality’ of disposal, like the making of safety and disposal futures (Chapter 5) relies on boundary work (Gieryn, 1983). GD safety making and argumentation rest on separations between the human and the nonhuman, the aboveground and the underground, storage and disposal. In her seminal work *Purity and Danger*, Mary Douglas (1966) argues that disposal is about creating boundaries and order. It is about making waste, a ‘matter out of place’, invisible through practices of disposal. Disposal, then, emerges as a way of ordering social life; it helps to make sense of society, and helps society to make sense of the world (Douglas, 1966). Zsuzsa Gille (2013) in turn has argued that theorising waste as matter out of place like Douglas does needs more justification. Once disposed of, waste, Gille argues, is no longer seen as a matter out of place. Through disposal waste is emplaced in a space society has designated and designed for it. It becomes ‘matter in place’. Disposal practices, then, in Gille’s reading, make waste determinate. Disposal in part is what establishes matter as waste. However, Gille also argues that if waste is defined through its spatiality (matter in/out of place), practices (beyond disposal and disposal site) that make material waste need to be explored and demonstrated.

Taking cue from Gille, Hird (2013b) notes that disposal ostensibly renders waste as matter in place. Yet, this “out-of-sight, out-of-mind rendering determines certain stuff to *be* waste and *remain* waste, and belies alternate renderings, such as waste as lively and flowing” matter (Hird, 2013b: 29, emphasis in the original). For Hird, conceptualising disposed-of waste spatially as ‘matter in place’ denies the liveliness and vitality of waste matter to move and evolve, to become and unbecome something. Waste as ‘matter in place’, Hird argues, is a pacified reading of the matter. Accordingly, Nicky Gregson and Mike Crang (2010) note that much social science scholarship on waste, in fact, overlooks waste. Instead, existing work tends to focus on the *management* of waste, thus domesticating and circumscribing the liveliness of waste matter. Much of this holds true for the existing social scientific work on GD that focuses on issues around risk perception, public acceptability and governance of GD projects (Kuppler, 2012). National participatory processes have been analysed closely (e.g. Durant, 2007; Lehtonen, 2010a; MacKerron and Berkhout, 2009), but waste itself, aside from few exceptions (e.g. Gregson, 2012), is largely absent in this work.

Elsewhere, discussing landfills, Hird (2013a) has described the vitality of waste; how in landfills waste encounters, engages and forms leachates with its surroundings. Waste when disposed of it is still lively. It moves within the disposal site or landfill with the potential to defy its containment, to leak out, configure and reconfigure the world. Disposal, rather than an end point, is therefore better conceptualised as a phase in the life of matter – a point to which I will return shortly.

Waste is an ambiguous linguistic signifier Hird (2012). Anything and everything can become waste. The perceived unusability or worthlessness of matter can be seen as the beginning of its transformation into waste (Kennedy, 2007). With respect to the indeterminacy of wastes proposed by Hird and others, Gille notes “if waste is not by essence waste but it becomes waste, then what is needed is to demonstrate by what practices in what […] places the matter […] was made into waste to begin with” (Gille, 2013: 3). How and where waste becomes or is made waste is important for understanding how containment and disposal are envisioned, justified and engineered in GD projects. While containment could be seen as just a matter of engineering, this ‘technical realm’ of containment is mediated by legislation, risk assessments, envisioned needs, imaginations, and discursive performances of containment. The makings and unmakings of waste are matters of definition and policy decisions (Chapter 4 and Chapter 6). Disposal does not necessarily mean that matter is unwanted or no longer has any value. Particularly with regards to nuclear waste, the classification of matter as waste or asset, and the readings of its (potential) value defy easy definition.

The labelling of nuclear waste is not necessarily connected to the politics of value (Gille, 2010). In Chapter 6, I will explore the waste ontologies of the UK and Finnish disposal cultures (see Chapter 3). I will propose that the emplacement of nuclear waste in a GDF *does not necessarily* render matter to remain waste. GD is not necessarily the end point for nuclear waste, but it can be reimagined and the GDF remade as storage. Nuclear waste can unbecome through radioactive decay, but it can also be unmade through political decision-making (Chapter 4). Thus, following Kevin Hetherington (2004) I posit that disposal can be seen as the making of (temporary) absence.

Disposal, like waste, thus is a temporary rather than an absolute category. “Disposal”, Hetherington writes, “is never final […] but involves issues of managing social relations and their representation around themes of movement, transformation, incompleteness, and return” (Hetherington, 2004: 157). He notes that often missing in social scientific literatures on disposal is this notion of disposal as *continual making and holding things absent*. Instead the focus has been on getting rid of things or meanings (e.g. Douglas, 1966). Yet disposal, Hetherington contends, is more about placing absences than about waste; it is spatial as well as temporal doing. In line with Hird, he argues that matter out of place that is made absent through disposal is “only ever moved along and is never fully gotten rid of”, rather it “has a motility as well as a mobility – it moves between a status of presence and absence” (Hetherington, 2004: 162). Marilyn Strathern, similarly, has proposed that “those involved in the activity of waste disposal know that one cannot dispose of waste, only convert it into something else within its own life'' (Strathern, 1999: 61). Together the notions of the liveliness of waste and the temporality of disposal suggest that waste matters cannot fully be managed through disposal practices.

While wastes are made absent through their placement in disposal facilities and sites, they cannot be fully disposed of or contained. This is the case particularly with nuclear waste, whose multi-millennial lifespan defies and exceeds the ability to engineer containment. The lifespan of nuclear waste surpasses that of any engineered structure. Even on shorter timescales (hundreds rather than millions of years), the problem with containment, Hird writes, is that it is only ever temporary. Eventually, even landfills “spill and leak […] as such, landfilling and waste management generally, introduces a resilient tension between determinacy and indeterminacy" (Hird, 2013a: 465). Accordingly, Peter van Wyck (2005) defines nuclear waste not as matter out of place, but as *matter without place*. Nuclear waste, he postulates, is a "kind of waste that resists its own containment. A kind of waste that operates in a radically different temporality; it is material whose toxicity requires a different conception of history and time" (van Wyck, 2005: 5). So, I would argue that the temporality of nuclear waste defies the notion of GD as an end point (I will return to this point further below). Moreover, the toxicity and radioactivity challenge the pacified image of nuclear waste as manageable or containable material. As matter without place nuclear waste defies containment. Just how it does this and what kinds of challenges this imposes on making safety claims and safe futures will be explored in Chapter 5.

Nonetheless, Nicky Gregson (2012) has observed that in public representations of nuclear waste in the UK, nuclear waste has been stripped of its toxicity and radioactivity; stripped of its nuclearity (Hecht, 2007). Nuclear waste, Gregson argues, has been pacified in public representations, even though it is the corrosive and radioactive vitality of the waste that governs its concentration and confinement at places such as Sellafield, where the UK stores approximately 74% of all the UK's nuclear waste (NDA, 2017a). Gregson writes about her visit to Sellafield and own experience of the vitality of nuclear waste by describing how "in the HLW store radioactive waste is felt rather than seen. As one stands on the storage silos below that hold vitrified waste, one senses both the heat and the burden of responsibility that attaches to this stuff" (Gregson, 2012: 2011). Her description of the waste and how it can be sensed even through thick layers of glass and concrete seem to attest to the liveliness and vitality of waste. Gregson further claims that while the vitality of radioactive materials in relation to the human is appreciated, the colonising materiality of nuclear waste, its vitality that "ruptures the integrity of all that comes into contact with it — be that organic or inorganic life" is less acknowledged (ibid.: 2016). It is this colonising liveliness and vitality, Gregson argues, that is absent from public representation of nuclear waste. Instead of the describing the vitality and ability of waste to harm and colonise organic and inorganic lifeforms, public representations contain and pacify wastes in tabular representations of the volumes, weights, and activity levels of different waste categories. These representations, Gregson posits, are often accompanied by images of high-level waste (HLW) storage facilities at Sellafield in which nuclear wastes are only present through their implied containment under “circles coloured yellow and black on the floor” (Gregson, 2012: 2012) (see Figure 3).

The visual as well as the tabular representations show nuclear waste as already confined and disciplined, translated and translatable into neat figures and spaces. These representations and the different ways nuclear waste is categorised and sub-categorised into classes by its levels of radioactivity, relative volumes and weights, present it as “not only manageable but already being managed, thus [the waste problem is] always potentially solved” (Gille, 2013: 2). In public representations waste is, thus, deproblematised. Kevin Hetherington (2004) and Timothy Morton (2013) have objected to the finality implied by the representation of waste as controllable matter, since this implies that waste can be managed in a permanent way.

Figure 3. Nuclear waste storage in the Netherlands. Circles on the floor marking the presence of nuclear waste. Creative Commons.

Morton argues that nuclear wastes “are not objective lumps limited in time and space, but unique beings” (Morton, 2013: 122) that inevitably need to be taken into count in designing the GDF, since “we can’t unthink our knowledge of them” (Morton, 2011: 86). The GDF design (see Figure 1 in the Introduction) will be engineered to contain, not the pacified waste of public representations, but the long-lived hazardous waste that currently sits in aboveground storage facilities. This, as Morton suggests, means that the GDF “design must account for thousand, ten thousand, and hundred thousand year timescales” (ibid.). It must account for a long-lived radioactive hazard, not tabular pacifications of nuclear waste. Public representations of manageable waste can thus be seen to lie in opposition to the engineering and design demands the radioactivity and hazardousness of nuclear waste impose on GDF construction. The UK Radioactive Waste Management Ltd. (RMW) describes the GDF as a

> highly-engineered facility, located deep underground, where the waste will be isolated within a multi-barrier system of engineered and natural barriers designed to prevent the release of harmful quantities of radioactivity and non-radioactive contaminants to the surface environment. (RWM, 2016a: 1).

Not only is waste emplaced deep underground, but also within multiple barriers to prevent its easy return to the surface. The design of the GDF and the materials used in the EBS for isolating waste underground reflect the materiality and characteristics of the waste that will be disposed of in the GDF (see Chapters 4 and 5). The GDF is “designed to ensure that the wastes are isolated and contained for the long term after disposal by passive means” (RWM, 2016b: 40). Together the emplacement of waste deep underground behind multiple barriers, the notion that waste needs to contained for the long-term through passive means are suggestive of the vitality, rather than the pacificity and easy manageability, of nuclear waste.

Passive containment of nuclear waste envisioned by GD concepts signifies an anticipated absence of lack of human intervention in the operations of the GDF after the facility has been sealed and closed. As I will explore in Chapter 5, the human is posited as an unreliable guardian of nuclear waste, because of the radically different timescales of the human and the nuclear. Instead the isolation of waste and the provision of safety into the very distant future are delegated to the underground and the GDF. In contrast and in relation to the human, the GDF has been posited as a more reliable and predictable guardian of nuclear waste in the long-term by the international nuclear waste community. Where human actors are seen as fickle, the GDF is ascribed the ability to provide safety in the very long-term. Recently, however, social scientists have begun to question the stated reliability of the GDF, as well as the finality of GD as a permanent solution to the management of nuclear waste. Because of the multi-millennial need to contain nuclear waste and the challenge this timescale effectively imposes of engineering and knowledge making practices, social scientists have proposed that instead of conceptualising GD as an end point, GD should be treated as a long-term sociotechnical experiment (e.g. Bergmans, Landström and Schröder, 2014; Landström and Bergmans, 2015, Schröder, 2016).

A long-term sociotechnical experiment

From Science and Technology Studies (STS) we have learned that ’artifacts have politics’ (Winner, 1980). Artefacts embody political visions of society and affect the ways in which humans relate to their environment and to each other. In Finland for instance, GD has been politically defined to represent the “overall good of society” (MTI, 2000). This has been the main justification supporting the implementation of GD. As such, the GDF itself can be seen as invested with visions of a desirable future – one in which society as a whole is seen to benefit from the construction of the GDF.

Instead of thinking of the GDF simply as a technological system or an artefact, I will, following existing social science work on GD (e.g. InSOTEC, 2014), conceptualise it here as a sociotechnical combination. Rather than a technical system surrounded by a social context, the GDF is entangled with visions of social good, desirable futures, but also concerns about the future and nuclear things. Where, for many technologies, the relationship between ‘social’ and the ‘technical’ is uncontroversial (see e.g. Bijker and Pinch, 2012), the controversy around GD has not settled yet. Possible societal oversight over the GDF continues to be debated for instance through discussions about the inclusion of monitoring technologies in the GDF. These technologies could allow society to keep an eye on the GDF post-closure. Questions have emerged over what would be monitored, what would be the purpose of monitoring, and how would societies respond if the monitors generated and sent unusual data from the GDF. Bergmans et al. (2012) found differing perspectives on the role of monitoring between technical experts and concerned citizens. While technical experts viewed monitoring as “a matter of performance confirmation, a tool for validating the safety case underlying repository construction”, concerned citizens viewed monitoring as a tool for “critical scrutiny of safety, an instrument for acknowledging uncertainties and detecting emergent problems in a repository” (ibid.: 22). Thus GD deals with highly controversial issues: highly radioactive nuclear waste and unknowable (see below) very distant futures, but it also continues to be a controversial technology, as its ability to provide (long-term) safety remains contested.

The GDF is expected to contain nuclear waste for one million years. This timeframe of one million years has been, and remains, contested among nuclear waste management experts, as I will explore in Chapter 5. Nonetheless, one million years is an internationally standardised timeframe for GD safety assessment. From a human perspective, one million years proposes certain foreverness, a notion supported by the labelling of the GDF as the first posthuman structure (Levitt, 2011). The conceptualisation of the GDF as a posthuman structure can be taken to signal the discrepancy between human and nuclear timescales. In the first instance, it underlines the longevity of nuclear waste and the much shorter human existence. Secondly, the notion of a posthuman structure implies scientific and engineering ambition. Despite the discrepancy between human and nuclear times, the international nuclear waste community has established GD as “*the ultimate end-point* for managing long-lived radioactive waste in a safe manner which will protect human and the environment passively for the required long time scales” (Schröder, 2017, my emphasis). This notion of GD as an end point, as I mentioned above, has been challenged by some social scientists.

Definitions of GD that highlight uncertainty rather than permanence have emerged from the work produced by InSOTEC.[1] Where Landström and Bergmans (2015), have proposed that GD should be viewed as an 'on-going socio-technical experiment', others yet have described GD as a "controlled, *open-ended exploration* towards a possible solution" (Kallenbach-Herbert et al., 2014: ii, my emphasis) or as a 'hypothesis' whose functionality is yet to be empirically demonstrated (Bergmans and Schröder, 2012). The reading of GD as an experiment or a hypothesis stems from the extremely long and slow geological, geochemical and geophysical processes as opposed to the short-term experiments that are conducted to map and predict those processes in the present. Moreover, not all geochemical and geophysical processes are necessarily replicable in the lab. Thus, there will be knowledge gaps and the workability of the GDF cannot be guaranteed in the present. Rather than an established solution to the long-term management of nuclear wastes, GD should be treated as a 'technology in the making' (Bergmans, Landström and Schröder, 2014). Because of the discrepancy between the lifespan of nuclear waste and lab experiments, tens even hundreds of thousands of years need to pass until present-day models and calculations of the safety of GD are proven right or wrong. What Bergmans, Landström and Schröder mean by 'GD as a technology in the making', is that GD should not be posited as a singular end point for nuclear waste management. Instead, she claims, GD should be treated as a means to attain *a* safe option for the management of nuclear wastes in the long term. Because GD's ability to deliver what it promises – a safe long-term future – cannot be guaranteed today or in the foreseeable future, GD should not be the sole policy aim, but a tool for reaching a safe future.

By accepting GD as an open-ended experiment, as a means, but not necessarily the end, towards safety, Bergmans, Landström and Schröder posit, GD projects can draw from contestation. Instead of striving for consensus, controversies can be mobilised as a means of feeding technical democracy (Marres, 2005). This could also expand public and stakeholder engagement in

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[1] InSOTEC (International) Socio-Technical Challenges for implementing geological disposal) was an EU funded project that ran between 2011 and 2014 and aimed to identify the main socio-political challenges for implementing geological disposal and their interplay with technical challenges.

GD projects beyond the siting process to construction and operation phases, closure and post-closure. Similarly, Ibo van de Poel (2011) has argued that a focus on nuclear technology more broadly as an experiment could shift debates from the acceptance/rejection dichotomy towards a deliberation of the conditions and situations in which experiments with nuclear could be acceptable. Focusing on the situation of the experiments could be a way of sticking with them, instead of outrightly rejecting them. Treating GD as an open-ended experiment, allowing space for debate and contestation, would work both as a means to increase democracy and public engagement in GD projects and also to create space for alternative futures and waste management solutions.

Jantine Schröder (2016) has further expanded the idea of GD as a sociotechnical experiment, drawing on the work of van de Poel (2011). Van de Poel argues that the experimental nature of all nuclear power technologies makes it difficult to predict their risks before implementation. With regards to reactor technology this is because of the impossibility of testing disaster or accident scenarios, such as earthquakes, in realistic circumstances. Thus, models and simulations of accidents are based on unverifiable assumptions that cannot be fully tested until the reactor is operational, and the reactor's resilience against earthquakes, for example, remains hypothetical.

In this sense GD, van de Poel posits, is even more experimental than nuclear reactor technology. While future risks of GD have been estimated, significant uncertainties remain since many scenarios and paths of GDF evolution cannot be tested in the lab (e.g. Macfarlane and Ewing, 2006; Shrader-Frechette, 1993). Uncertainties emerge, for example, from the impossibility to know geochemical and geophysical processes in the very long-term, but also from the impossibility of predicting how people in the (distant) future might relate to the GDF. Will they leave it alone? Will they be intrigued by it? While existing literature suggests that the predictability of the GD future is limited in the present and field tests cannot represent future real-life situations, empirical understanding is needed to gage how such limitations might affect the making of safety claims and arguments in a situation in which non-linear long-term developments a system are difficult to map, some hazards might be overlooked as wholly unimaginable or unthinkable, and GD retains its experimental character. This thesis aims to trace some of the ways in which the UK and Finnish disposal cultures seek to make safety out of uncertainty.

Uncertainty about the future, van de Poel argues, renders GD a social experiment. Social experiments, he notes, differ from ‘standard’ (scientific) experiments in three respects. First, social experiments do not take place in the lab. Rather, they are transported into the ‘real world’. Second, since they take place in the real world, social experiments might not be recognised as experiments; thus monitoring and data collection might be absent. Finally, the above reasons render social experiments less controllable than standard experiments. This makes it more difficult to contain hazards during the experiments, while it might be equally difficult to determinate experiments, which might have irreversible consequences. Drawing on van de Poel’s work, Schröder differentiates between standard and technological experiments, and further between standard and sociotechnical experiments. Technological experiments, Schröder posits, are less interested in ‘truth’ than in the application of artefacts and methods in ‘real life’ situations. According to her, technological experiments such as Posiva’s FISST (mentioned in the Introduction) aim to demonstrate the functioning of a technology. Yet, the difficulty of extrapolating from the lab to real life conditions inserts a gap between the production and application of knowledge, the development and implementation of technology. Thus, the implementation of GD precedes the verification of its functioning. This makes GD a technical experiment.

What makes GD a sociotechnical experiment, Schröder observes, is the entanglement of the social and the technical that is absent from official representations of GD safety making. Official discourses on making safety and containment rely on delegating safety (Latour, 1992) to the GDF and on the absence of humans. Schröder maintains that while safety and the containment of nuclear waste is delegated to the GDF, the delegation can only work if humans *agree* to stay away from the GDF. While the GDF is passively doing safety, humans must refrain from engaging with the GDF in the future for the safety provision to be effective. Safety, in this sense, “is an interactional […] process that needs to be sustained, not only by the delegated but also by the ‘delegator’ and its descendants” (Schröder, 2016: 698). In this reading, humans are involved in the making of long-term GD safety by agreeing to remain away from the GDF. By highlighting GD as a ‘final’ and passive technology, the international nuclear waste community makes the delegation of safety clear. Humans are not expected to be involved in the (long-term) operation of the GDF. Safety is based on an imagination of nuclear waste “leaving the social world behind” (Bloomfield and Vurdubakis, 2005: 738), and on broader ‘world-reduction’ (Jameson, 1975), as I will explore in Chapter 5.

The obscuring of the role of the social in the making safety, Schröder posits, potentially jeopardises the delegation of safety, as it overlooks the responsibility of the delegator. Instead, approaching GD “as a ‘social experiment’ highlights the relevance of the social, human realm in contrast with the largely technical, nonhuman description of the technology by the international radwaste community” (Schröder, 2016: 669). In addition, conceptualising GD as a ‘sociotechnical experiment’ sensitises us to the “implausible idea that once knowledge ha[s] determined plans and objects, then realisation w[ill] ensue without care and caution being necessary any more” (Latour, 2001:11). The notion of GD as an end point assumes that safety will readily follow and flow from knowledge and disposal plans. The conceptualisation of GD as an end point overlooks the complexity and the open-endedness and negotiability of safety making. Containment is not just the product of the passive safety provided by the EBS, but it is also made by the absence and lack of human involvement. In this sense, containment is a contract between present and future generations that can be made and unmade. Combined with the liveliness of waste, the potential to unmake containment through human intervention ensures that the notion of the GDF as the end point to nuclear waste can be contested. Appreciating GD as an experiment, rather than as an end point for nuclear waste (management), leaves space for alternative futures to emerge and for alternative sociotechnical combinations to produce containment and safety in the long-term.

Closely connected to this idea of GD as an ‘on-going experiment’ is the notion of retrievability, which I will explore in Chapter 6. Retrievability is the ability to retrieve waste from the GDF after disposal. Together with reversibility (the ability to reverse decisions made during the implementation process), retrievability allows space for alternative futures, should they emerge, and in this sense it can also be read as a potential extension of society's control over nuclear waste. Retrievability and reversibility are means of dealing with uncertainty and can be mobilised in different ways. Pointing to the examples of France and Switzerland, Bergmans, Landström and Schröder (2014) note that in France reversibility is a political tool for managing uncertainty and maintaining sensitivity to changes in France's nuclear waste inventory. In Switzerland, in contrast, retrievability is perceived as a technical translation of a social demand for dealing with uncertainties. The main argument for retrievability, however, is its provision of flexibility towards unexpected technical developments in the long-term management of nuclear waste. Even after the GDF is closed, retrievability fosters the potential for alternative futures to be made and enacted upon. Retrievability thus has the potential to blur the boundary between disposal and storage. By creating flexibility and potential for alternative futures, the notion of retrievability underlines the open-endedness of GD. In any case because of the exceptional timescales involved GD, Bergmans and Schröder (2012) argue, it is a more open-ended project than statements of technopolitical consensus around GD let through.

The open-endedness and experimental nature of GD provide a starting point for the examination of GD as a form of future making. The longevity of the radioactive threat posed by nuclear waste necessitates its containment for multiple millennia, even for one million years. However, the very timescale of necessary containment escapes contemporary capacity to know the future and the safety claims made of the GDF's ability to contain nuclear waste will not be verifiable in the foreseeable future. The deep future of GD, thus, extends to spaces beyond knowledge, and attempts to predict the future will always be characterised by uncertainty. Therefore it is imperative to trace how safety claims are made in situations characterised by uncertainty, and this is what I will do in this thesis.

2.3 Future as the end of certainty

Al Gore (2013) has described the future as the end of certainty. The deeper into the future we look, the greater the uncertainties become (Adam, 2008).

Technologies often exert unintended consequences; they synchronise a range of elements and occasionally form new systems. This makes futures unpredictable (Urry, 2016). Adam and Groves (2007) posit that while the ability of contemporary society to create futures is unparalleled, our ability to know futures is dismal. Yet, the effects of future making in contemporary societies extend further and deeper into the future than ever before. Think nuclear for example. Nuclear technology is by definition connected to geological timescales, both in terms of its past and future. With the necessity to mine and refine naturally radioactive ores and minerals, and to dispose of wastes, contemporary society engages with a timescale beyond human understanding through nuclear technology. Ordinary practices of future making such as forecasting, technology assessment, backcasting and roadmapping (Borup et al., 2006; Rappert, 1999) are too limited in scope when it comes to making futures through GD. John Urry has noted that future making often “involves the assumption of ‘business as usual’ [that] involves seeing some feature of the present as the mechanism in how people’s lives will predictably unfold in the future” (Urry, 2016: 95). Such an approach to future making is incompatible with GD that extends well beyond human times and experience. Moreover, what makes GD an interesting case of future making is that “risks are not only the possible results but the given point of departure of innovation: the waste is there, making its management inevitable and the principle desirability of innovation incontestable” (Schröder, 2016: 690-1). GD future making begins from the future and (future) risks, which exert their influence in and on the present. It is the incompatibility between human and nuclear times – the eventual loss of human ‘control’ or ability to manage nuclear waste in the long term – that impels action in the present. Morton, for instance, posits “the future of plutonium exerts a causal influence on the present, casting its shadow backward through time. All kinds of options are no longer thinkable without a deliberate concealment of the reality of radioactive objects” (Morton, 2013: 120). Like Schröder, Morton argues that nuclear waste and waste futures demand action in the present. Waste and waste futures demand fairly particular action, since ‘business-as-usual’, continuing surface storage, is no longer regarded as a reasonable course of action. Inaction, in Morton’s reading, can be justified only through deliberately ignoring the risks and hazards of nuclear waste matters. Moreover, with risk as the starting point for action, courses of action become limited. Nuclear waste then impels ‘us’ to treat them in particular ways to protect the liveable world from the risk of radiation. Nuclear waste “forcefully exert[s] […] *the imperative*” to do something about them (ibid.: 67).

Drawing from Morton, nuclear waste can be conceptualised a *hyperobject*. The notion of hyperobject refers to things (such as climate change or nuclear waste) that are distributed in spacetime beyond the human scale. They occupy a “high-dimensional phase space that results in their being invisible to humans for stretches of time” (ibid.: 1). Hyperobjects such as nuclear waste are sticky; they will “never leave us alone” (Morton, 2011: 82). They transcend space and time and underline the fragility of all entities. They do not respect boundaries humans have so carefully constructed between different entities, times and spaces. Rather hyperobjects readjust our sense of proximity to each other and other entities and “force us into an intimacy with our own death (because they are toxic), with others (because everyone is affected by them), and with the future (because they are massively distributed in time)” (Morton, 2013: 139). Because of “temporal foreshortening”, the radical discrepancy between nuclear waste and human lifespans, nuclear waste is “impossible to handle just right. This aporia gives rise to a dilemma: we have no time to learn fully about [them]. But we have to handle them anyway” (ibid.: 139). Facing this necessity, it is important to consider what kinds of futures nuclear waste as a hyperobject impels societies to envision and implement. What kinds of relationships and ontologies does nuclear waste imply in the present and the future – and for the future? What kind of future making is possible with and through nuclear waste (or GD), when nuclear waste transcends human existence and extends to the humanely unknowable future? These are some of the questions this thesis seeks to answer.

Thus far, drawing on literatures on futures, GD and hyperobjects, I have proposed that futures are made in the present. Morton has argued that hyperobjects such as nuclear waste “exert[s] downward causal pressure on shorter-lived entities” (Morton, 2013: 139). Humans are left to grapple with futures in the present. As such, futures also organise the present. George Marcus, for instance, notes how scientists are “constantly trying to understand the present by borrowing from a cautiously imagined emergent future” (Marcus, 1995a: 4). Scientific imaginations, Joan Fujimura (2003) concurs, are visions of future possibilities around which scientific communities and practices organise. Future imaginations can mobilise resources from the national policy level to research networks, research groups and individual researchers. The future and imaginations about the future can inform the course of action in the present by facilitating network formation, dissemination of knowledge (Brown and Michael 2003), and by shaping shared understandings of what kinds of futures are possible or desirable (Groves, 2013; Jasanoff and Kim, 2009). In this way, the future can be seen as a powerful agent in the present. Through speculations such as ‘what the future will bring’ or ‘what the future will be like’ societies project agency to the future in the present (Brown, Rappert and Webster, 2000). In contrast to the assertion of the non-existence of a perfect future in *The Hitchhiker’s Guide to the Galaxy* (see the beginning of the chapter), contemporary society tends to see the future as a space where things are perfected – the future portrayed as a ‘fancier version’ of the present (Marvin, 1990; Urry, 2016). The future is conceptualised as a space where the problems of the past are solved and wrongs a righted (Michael, 2000). GD is a case in point. GD explicitly imagines and seeks to produce a future that is safe, something that ‘business-as-usual’ storage arrangements cannot provide in the long-term. The UK RWM’s (the body responsible for the delivery of UK GDF) vision is a “*safer* future by managing radioactive waste effectively, to protect people and the environment” (RWM, 2015: 3, my emphasis). Safe GD futures are imagined in the present by contrasting GD with current nuclear waste management practices, namely surface storage. Storage and the aboveground, as I will illustrate in Chapter 5, are construed riskier as a technology and space than the GDF and the underground. In relation to the present situation then, the future as imagined through GD is seen as a space where things are improved, problems are solved and risks replaced by safety.

Adam and Groves remind us that making futures is simple. Everything we do sets futures in motion, yet these ‘futures in motion’ are not predefined or determined – rather they are real unrealised present possibilities. Our actions in the present inform what futures are possible, and how they might unfold. While everything can be seen to set futures in motion, knowing these futures in the fullness of their effects is challenging. The effects of nuclear future making for instance are increasingly dispersed in time and space. Knowing and predicting the effects of nuclear radiation is difficult, as they can be latent and emerge independently of their sites of production. Nuclear things, Adam and Groves (2007) note, have the capacity to foreshorten, spoil and eliminate futures. In the Nuclear Age, continuity is no longer a given. The Nuclear Age, as we noted in section 2.1, has been conceptualised as End Time (Anders, 1962): an era where the elimination of future is a potent, present possibility. Here, disruption (sometimes deadly) becomes a collective potential. Nuclear future making always contains a nuclear risk, always contains the risk of a future taken or spoiled.

Adam and Groves differentiate between future taking and future making and trace the difference between future taking and making through the relationship between ethics, action and knowledge (see Figure 4). Future taking, they hold, focuses on the short-term. Here, responsibility is tied to knowledge – meaning that we are only responsible for those consequences of our actions that can be known or predicted in advance. We (can) “take a chance, hoping to be excused from moral blame if it can be demonstrated that the future consequences of our actions at the time could not have been ‘reasonably foreseen’” (Owen et al., 2013: 28). In future taking the unknowability of the future justifies actions in the present and forgives the potential negative futures consequences of actions taken in the present. The future here is imagined through and as the property of the present, as *present future*. The notion of present future treats the future, from the standpoint of the present, as an empty space to be colonised and moulded by the present. On the other hand, we have future making. Here, the distribution of responsibility changes. Our responsibility flows directly from our actions rather than from the known or predictable consequences of these actions.

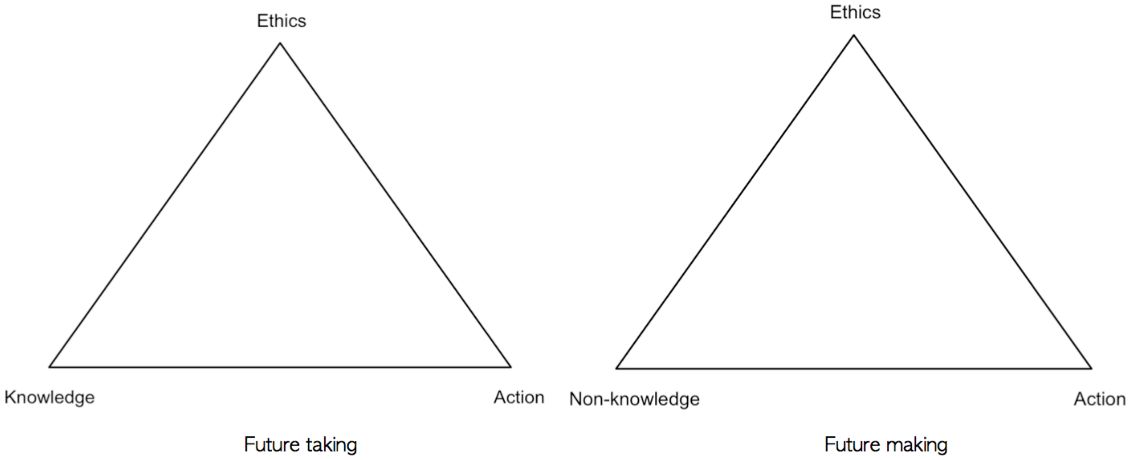

Figure 4. Future taking and future making (Adapted from Adam and Groves, 2007)

This is where responsibility is no longer tied to knowledge. Rather, our responsibility flows directly from our actions regardless of whether we can predict or not their future consequences. Morton has weighed the responsibility of the present to the distant future. He argues that our responsibility to extends directly to the unimaginably vast multi-millennial futures, because our “smallest action now will affect that time in profound ways” (Morton, 2013: 60). He argues that ecological awareness, a flat ontology (see section 2.4 below), compels us to think about the ‘future future’, the distant times we cannot know. Ecological awareness increases our intimacy with greater number of beings than the human, and vaster times than the present. While ecological awareness in the first instance stands for the denial of human exceptionalism, it is also the rejection of the preeminence of the present. While the future imagined through GD is distant, nuclear waste has brought it nearer. Nuclear waste has, in a sense, created equivalence between the present and the future. Although the future is strange, it exists in an intimate relationship with the present. We can never fully know or experience the future or account for it, yet the ethics of nuclear future making guide our doings towards the very distant, unknowable, future (Morton, 2013). In place of a present future of future taking we, thus, have a *future present*.

The notion of future present, Adam and Groves hold, “positions us with reference to potential impacts of present actions on future generations who have to cope with the consequences of our inventions and interventions” (Adam and Groves, 2007: 176). A future present is a space owned by future generations in which we are mere trespassers. Unlike present futures that are out there waiting for us to colonise them, the notion of future present highlights that the future has its own present. It is already occupied. In a future present we, the present generations, “require forgiveness from successors for our future making (ibid.: 169). In tune with Morton, Adam and Groves argue that “knowing ourselves to be dependent on forgiveness from successors for the unintended consequences of our actions becomes important, as it induces an approach to the future that is tempered by responsibility to others as yet unborn” (ibid.: 170). While Morton argues that hyperobjects such as nuclear waste create equivalence between the present and the future, Adam and Groves remind us that in order to care for the future and to carry responsibility for future times, we need to appreciate that we, nonetheless, are in an asymmetrical, non-reciprocal relationship with future generations. Despite the intimate relationship between the present and the future, the future nonetheless is a stranger. We will never know it firsthand, but this does not mean that we are not responsible for it. The standpoint of a *future present* enables us to trace our actions to their ends and to appreciate our responsibility for their latent effects. With the shift from present futures to future presents, responsibility is not tied to the known, but to non-knowledge. The unknowability of the future no longer absolves us from responsibility. Rather responsibility needs to flow directly from action. Doing, rather than knowing, implies and implicates the responsible. Doing together with the hyperobjectivity of nuclear waste, ensures that nuclear future making has “become a cosmopolitan endeavour” (Adam and Groves, 2007: 184). When the effects of our actions traverse beyond knowledge, responsibility becomes grounded in social debate. Instead of knowledge, social debate and ethical judgements of right and wrong guide future making.

The epistemic and ontological challenge in making futures through GD is that nuclear waste is not forever, but instead offers a very a large finitude (Morton, 2013), a very distant future. Morton argues that in a sense thinking about ‘forever’ is easier than thinking about very large finitude. “Forever”, he writes, “makes you feel important. One hundred thousand years makes you wonder whether you can imagine one hundred thousand anything” (ibid.: 60). Very long timescales are abstract and thus difficult understand. Whereas forever has certain certainty to it, the *deep future*, the one million years of containment necessitated by the long timescale of nuclear waste and international standard practices, is beyond predictability or ethical and political calculations. Nuclear waste is futural. It demands that we carry responsibility not only for the known consequences of our actions, but also for our doings in the present regardless of our ability to know the futures we make. Nuclear waste swaps the certainty of the now to an uncertain future and challenges common sense conceptualisations of time.

Deep future

John McPhee coined the term ‘deep time’ in 1981. The term highlights the “apparent insignificance of the span of human existence in the face of geological process” (Fearnley et al., 2017). The geological timescale does not open up instinctively. It is difficult to grasp and short-term perspectives and visions of futures and societal challenges have often been dominated by economics and politics. Accordingly, Stephen Jay Gould holds that the geological time presents a timescale so vast that humans struggle to understand it. He muses that while “an abstract, intellectual understanding of deep time comes easily enough - I know how many zeroes to place after the 10 when I mean billions. Getting it into the gut is quite another matter. Deep time is so alien that we can really only comprehend it as metaphor” (Gould, 1987: 3). Deep time is at odds with the pace of everyday life and everyday experiences of time. Yet, as we saw in section 2.2, short-term perspectives of time will not do with GD. In order to make safe futures through GD, we have to try and foster geoscientific understandings of time. The ethics of hyperobjects such as nuclear waste, Morton writes, “is directed toward the unknown and unknowable future” (Morton, 2013: 123). The future of nuclear waste is not one we can predict accurately, but a ”*future future* that is radically unknowable” (ibid.: 61). Nuclear waste lives, evolves and decays on a geological timescale. In contrast to human existence, it operates in deep time – and thus demands a move away from short-termism.

Deep time is beginning to have tangible material meanings outside geosciences. A few centuries ago, concern about the planet’s material state in a millennium might have seemed misplaced. Now, with nuclear waste to be disposed of and with oceans littered with plastic, the fragility of the planet, the effects of human activity are being brought to the fore. “Not only is our species increasingly vulnerable to the geologic”, Elizabeth Ellsworth and Jamie Kruse write, “we also have become agents of planetary geologic change” (Ellsworth and Kruse, 2012: 8). Unsurprisingly, perhaps, a number of artists, designers, and philosophers have been inspired by deep time and are now describing it and engaging with it through their work. The Long Now Foundation was established to “provide a counterpoint to today’s accelerating culture and […] to foster responsibility in the framework of the next 10,000 years” (Brand, n.a.). Together with the Long Now Foundation art initiatives such as *Nuclear Futures* (2017) that originated in Australia, *The Nuclear Culture Source Book* (Carpenter, 2016), exhibitions such as *Perpetual Uncertainty: Art in the Nuclear Anthropocene* curated by Ele Carpenter and currently touring Europe, and the documentary *Into Eternity: A film for the future* by Michael Madsen (2010) have began to visualise and imagine the effects of nuclear activities deep into the future, but also to situate geological time as a condition of the present. While social scientific literature is increasingly engaging with the geological timescale of GD, it has, for long, been surprisingly quite about deep time (Bloomfield and Vurdubakis, 2005; Ialenti, 2014a, 2014b). Similarly, futures and posthuman studies and the sociology of time have mentioned nuclear radiation or waste only in passing (e.g. Adam, 2008; Morton, 2013). Much of the existing literature on the future of GD focuses on the challenges of communicating nuclear threat, across millennia, cultures, languages and generations (e.g. Benford, 2000; Piette, 2016; Sebeok, 1984).

Kristin Shrader-Frechette (1993; 2005) has addressed GD issues from intergenerational responsibility to the epistemological ability of modeling practices to predict multi-millennial timescales. Paul Bloomfield and Theo Vurdubakis (2005), conversely, have presented the Yucca Mountain disposal project in the US as a case study for processes of boundary making pushed to extremes. Vincent Ialenti (2014a) has examined the relationship between GD pasts, presents and futures further. Focusing on the Yucca Mountain project, he has proposed GD as a space where “relations between the living societies of the present and the unborn societies imagined to inhabit distant future worlds are invented and reinvented” (Ialenti, 2014a: 41). His work examines how the US nuclear waste regime draws on familiar legal figures and tripartite rule-factsjudge adjudicatory relation from the past to demonstrate repository safety in regulatory horizons that extend up to a million years into the future. Elsewhere, Ialenti (2014b) notes how the nuclear waste safety experts are equally, if not more, preoccupied with short-term project deadlines and temporalities of daily life than the very long future of the disposal project. The long future, he observes, faded into the shadows as shorter term horizons of career stages, five-year plans, contingency plans, funding politics, deadlines and so on captured his participants' imaginations more vividly. The conclusion Ialenti draws from his ethnographic work is that "the short-term futures of project funding politics and the inner-workings of multidisciplinary scientific collaborations […] are worthy of much greater social scientific scrutiny" (ibid.). He notes further that a sensitivity to the nuances of shorter term challenges, such as retirements or career-changes of key personnel, training and intergenerational knowledge transfer, helps to illuminate how unexpected events in the present can "potentially shake nuclear waste management projects' stabilities" (ibid.). This, by extension, can shake the ability to make safe futures through GD. Paying attention to these contemporary events and challenges, and how they intertwine with the multi-millennial timescapes of GD can begin to sensitise us to some of the ways in which the presents and futures of GD are in an intimate relationship (Adam, 1998).

Despite the increasing attention to deep time and the future of GD, existing work speaks little of the material encounters and makings of deep time. In his discussion of deep time as an anthropological problem, Richard Irvine notes how late 18th century geologists 'forcefully' advocated fieldwork as the "only way to come to terms with the 'huge solid facts' of mountain ranges, volcanoes, rivers and their drainage basins" (Irvine, 2014: 163). "Physical and sensual encounters with the landscape", Irvine notes, "were coming to be seen as essential [for] truly grasp[ing] the scale of the processes at work" (ibid.). Situated encounters with geological evidence, then, were considered the main avenue for understanding and producing knowledge about deep time. Thus, Irvine argues, deep time "is not purely an abstraction to be calculated, but a phenomenal experience to be encountered in the field" (ibid.: 170). Not just an abstraction or a metaphor, as Gould proposed, deep time is something that can be observed, and traced in geological formations. It is something that can be touched, something that affects us visually and tactually. How deep time is construed can, then, be conceptualised as an anthropological or sociological problem.

In this thesis, I move from deep time to deep future and examine the making of the deep future through GD projects. The problem with deep future is that "it is long [in] time and short in detail" (Cocks, 2003: xiv). At the heart of this thesis, then, is a concern about how the deep future and knowledge about the deep future are made in the present. I will propose that *deep future* is made, encountered and experienced in the lab, in the field and in public documents. I borrow the term deep future from the science fiction writer Stephen Baxter. I prefer the notion of deep future to that deep time as a way of underscoring the 'non-factual' and 'factual' conceptualisations of futures and pasts in general (Adam and Groves, 2007). Where deep time, as Earth's past, is situated in the realm of the factual, traceable and knowable, and as such is used to inform attempts to know the deep future, the deep future itself sits more solidly in the field of the speculative and the imaginative. Rather than limiting the deep future to time, I work it in all its spatiotemporal depth and propose that the future of GD is deep because it is unknowable, but also made unknowable. The future of GD is deep because it is out of reach

- Temporally: we simply cannot know such as vast time period, it escapes our knowledge making practices, and
- Spatially: the whole logic of disposal is based on designing an unreachable, undisturbed future underground.

GD aims to make an unreachable and undisturbable future. Claims about the safety of GD rest on the notion of 'defence in depth' (Tweed, Ellis and Whittleston, 2015). Depth, in spatial terms, as we will explore in Chapter 5, is mobilised as a vital safety factor, as the underground is constructed as a safer and more predicable space than the aboveground. On the other hand, in a temporal sense, depth decreases certainty. The deeper the future GD projects seek to map in the present, the greater the unreliability and inaccuracy of the knowledge produced. The deep future of GD escapes beyond the verifiable, the visible, the human. Thus to map the making of the deep future we must adopt a flat ontology, which is what I will turn my attention now.

2.4 The end of the world as we know it

Jamie Kruse (2012) notes that we are slowly beginning to appreciate the forces that extend to and from the deep underground, and the relevance of such forces beyond human time. Discussing the 2011 Fukushima accident as the effect of unimagined and unprepared for geological forces, she notes how the design of the Fukushima power plant, together with the earthquake and the tsunami coproduced repercussions into the distant future. In a brief instance, infrastructure that usually supports society through energy production was shaken into nuclear waste. The management of the power plant became a matter of managing the multi-millennial effects of nuclear technology (Molyneux-Hodgson and Hietala, 2016).

The effects of nuclear technology, be they accidents or waste matter, connect nuclear technology to geological timescales. The effects of nuclear technology cannot be bound in space and time, but rather they create a global community of beings (Adam, 2008). Nuclear radiation treats all entities it encounters symmetrically, and contaminates indiscriminately in time and space. As, such it is perhaps the closest society has got to the stuff of modernity (Latour, 1992). Radiation works invisibly from within, it is knowable only to cells beyond the detection capacity of senses. Radiation operates in ‘complex temporalities and time-space configurations’ and its timescale “exceeds human capability and concern” (Adam, 2008: 193) As such, radiation can be described as a hyperobject, as we saw above. It transcends, time, space and human capacity to know it. Nuclear radiation, as a hyperobject, does not differentiate between things, times and spaces, and so “there will be no “away” towards which we can throw” nuclear waste (Morton, 2011: 82). Instead, we need a “*flat ontology* in which there are no ideological twists and bends to carry away our physical and philosophical waste into some illusory beyond” (ibid., emphasis in the original).

Nuclear radiation, Morton argues, heralds the end of the world as we know it. Radiation treats entities it encounters symmetrically, and humans need to adopt a similarly symmetrical approach to the world. To make and to map the making of safe deep futures, humans need to let go of the hierarchies and separations we are so familiar with. Our view of the world, Morton argues is ‘landscaped’. It relies on the separation of the underground and the aboveground, nature and culture. Conceptualising the aboveground or landscape as ‘the world’ ignores the fact that landscape “depends on things like underground oil and gas pipes” (Morton, 2013: 106). The imagination of landscape-as-world ignores that the world is produced; the landscape “is an aesthetic construction” (ibid.) that relies on the invisibilisation of sociotechnical systems such as pipes. The imagination of landscape-as-world distinguishes between a foreground and a background. It presents the world as a container *in* which our lives take place. In contrast, in a flat ontology backgrounds and foregrounds dissolve; no place is special relative to another place. By letting go of the notion of landscape-as-world and by adopting a flat ontology, Morton argues, we have “the prospect of forging new alliances between humans and non-humans alike, now that we have stepped out of the cocoon of *world” (*ibid.).

Such a flat ontology, the collation of the aboveground and the underground, is what GD projects seek to avoid (Schröder, 2016). As we shall see later on, GD safety is constructed around the separation and contrast between the aboveground and underground. Social scientists, as we saw in section 2.2, have argued that GD safety is made through sociotechnical combinations (Schröder, 2016). GD safety, Schröder for instance has argued, rests on what happens both underground and aboveground. Catharina Landström and Anne Bergmans posit that in designing the GDF one of the most obvious needs is “to develop a 3D spatial understanding to account for underground processes in relation to local planning and development” (Landström and Bergmans, 2015: 387). Hosting a GDF, they observe, changes the spatial organisation of a community. Through hosting, the community extends from the surface to the underground, while simultaneously the underground comes to exert its influence on the surface. The rigid distinction between the aboveground and the underground becomes blurred. Landström and Bergmans ground their argument on Kiruna, a mining town established in Northern Sweden in 1900. Originally Kiruna was built a safe distance from the mine, yet over time mining operations have caused cracks to emerge on the surface and streets of the town. Because of these cracks, parts of the town are being relocated. The underground has come to assert its influence on the aboveground by extending its geological forces and ignoring aboveground attempts at worlding and organising society. What the Kiruna example aptly shows is the dissolution of the separation of the world into a foreground and background, aboveground and underground. It shows how the geological can shape everyday lives (Bennett, 2010). It shows the geological as a 'thing-become-force'; that can act and 'strike back' in irreversible and far-reaching ways (Kruse, 2012). With the cracking of the streets of Kiruna, the notion of living in a world loses its meaningfulness. Instead of thinking ourselves as being *in* the world, Haraway (2016) posits, we should think of ourselves as being *of* the world. Appreciating that humans, like everything else, are beings *of* the world (rather than beings in the world) enables us to bring in the missing masses (Latour, 1992); to adopt a flat ontology and to treat different entities and beings symmetrically as required by responsible future making. If we are to prolong the End Time there is a need become-with and compose-with other earthlings and things (Haraway, 2016). There is a need to let go of hierarchies, initiate and accept the end of the world-the-container. To understand the entanglements in the making of GD safety and futures, we need to let go of the exceptionalism of the human present. It is past time, Haraway argues, that we as humans understand that no single species acts alone. Rather, combinations of organic and inorganic beings make worlds and futures.

The invisibility of radiation, its effects that are untied to the time and spaces of production posit radiation as a phenomenon that escapes traditional Western definitions of the 'real', ways of knowing, and relating to the material world. In its corrosive, invisible vitality, radiation creates new ways of being, living and dying with unexpected company on a damaged planet (Haraway, 2016; Tsing, 2016). Accepting that company as a companion to whom human responsibility and care is extended signals new interspecies and intergenerational ways of relating in time and space. At the end of the world, Morton argues, "we are no longer able to think history as exclusively human" (Morton, 2013: 5), and Haraway concurs that we are living in "times of multispecies" (Haraway, 2016: 35).

2.5 Research questions

I In this chapter I focused on the need to begin with endings (the future as the end of certainty, the end of the world as we know it, GD itself as an end) as a starting point for tracing the making of futures through GD. I discussed the concepts of care, sociotechnical experiments, disposal as a temporal category, nuclear waste as a hyperobject, deep futures and future making. What these concepts share is a concern with time, the future as well as with matters of responsibility. They highlight the uncertainty and situatedness of future making and GD as a form of future making, and provide the starting assumptions and theoretical framework underpinning this thesis.

Following Morton (2013), I have here discussed nuclear waste as a hyperobject. Morton describes hyperobjects as things that are “massively distributed in time and space relative to humans” (ibid.: 1). Expanding into times and spaces beyond and without the human, nuclear waste has a future unknowable to humans. Yet disposal cultures (see Chapter 3) have been tasked with mapping and predicting that future. This distribution of nuclear waste in time and space beyond human experience and knowledge imposes challenges and introduces uncertainties to its management and the making of safety into the very distant future. It connects with Adam and Groves’ (2007) concern and distinction between future making and future taking. This distinction flags the precariousness of the making of futures that often has unintended consequences (Urry, 2016).

The concern with GD is that some of these consequences cannot be known in the present. This is what the concept of sociotechnical experiments (Landström and Bergmans, 2015) explicitly highlights. It helps to challenge the notions of ‘closure’ and ‘permanence’ mobilised by the international nuclear waste community to describe and justify GD. Instead, sociotechnical experiments points to the distribution of nuclear waste into the deep future and to the impossibility to accurately map and predict that future. The concept, thus, directs attention to the inevitable uncertainty of future making through GD – and, against the international waste community, encourages GD to be approached as *an* alternative rather than *the* alternative to producing and maintaining a safe future.

Finally, future making through GD can also be understood through the notion of ‘care’, following Tronto’s (1993) definition of care as everything we do to maintain a liveable world. Taking care of nuclear waste in official imaginations around GD is closely intertwined with visions of making safe futures. However, care, as was earlier, is a selective mode of attention and action. Plans to take care of nuclear waste through GD focus efforts to the implementation of a particular technological solution to the nuclear waste management challenge, and exclude other alternatives. In this sense, the notion of care can perhaps be seen as opposite to the concept of sociotechnical experiment. Yet, both concepts encourage us to ask questions about responsibility and about the kinds of futures envisioned to emerge through GD. In the first instance, they encourage us to question whether it is possible to take care of a hyperobject (nuclear waste) that will inevitably outlive systems and practices of care. What does safety mean and how is it argued for, if disposal is just a temporary sociomaterial configuration or an experiment rather than a ‘permanent’ solution? What kinds of futures are envisioned through GD? What kinds of futures and whose futures are at stake in the implementation of GD?

The concepts and literatures I have reviewed here provide a conceptual and theoretical framework for this thesis. They illuminate the openendedness and uncertainty of making (very distant) futures and underscore the need for a flat ontology for tracing the making of the very distant future through GD. Utilising these concepts, the overall aim of the thesis is to explore how the UK and Finnish disposal cultures make safe futures through GD. This aim will be investigated through the following research questions:

- How has nuclear waste been imagined in the Finnish and UK disposal cultures?
- How is safety made, into the deep, uncertain future?
- How are geological disposal, and the future, imagined within the Finnish and UK disposal cultures?

In the following chapter, I outline the research process I followed to answer these questions and explain how I addressed the overall aim of the thesis.

3 THROUGH THE LOOKING GLASS

> If anyone wanted ter find out some stuff, all they'd have ter do would be ter follow the spiders. That'd lead 'em right!
>
> - JK Rowling, *Harry Potter and the Chamber of Secrets*

'Following the actors' (Latour, 1987) is a canonical methodological trope in Science and Technology Studies (STS) and a method of investigation I relied on in this study. Following the actors to 'find out some stuff' has some implications. The imagination of following the actors requires practical choices from the ethnographer. Firstly, we need to define the 'actor'. Who and/or what are they? Secondly, we need to decide how, where and how far to follow actors. Despite the centrality of the notion, following the actors has remained a fairly vague methodological guidepost. Attila Bruni (2005) has noted that over the years little methodological guidance has been produced on how the imagination of following the actors can be translated into a practical method of investigation – particularly so if the actors to be followed are nonhuman. Additionally, following actors implies movement and dynamism that can be seen to problematise the field in some ways. How do we define our 'field' or is it defined for us by the movement of the actors? How far can and should we follow them within the constraints of the field and our own research?

To answer the first questions about actors, I observe the principle of symmetry that is central to actor network approaches (Callon, 1984). In the above paragraph, I already mention the notion of nonhuman actors that can be anything from spiders to flying cars and laptops. The principle of symmetry does not presume difference between humans and nonhumans, but treats these differences as relational. An actor can be anything doing something in a situation. Tommaso Venturini (2010) holds that the best way to identify an actor is to ask whether their absence or presence in a situation would make a difference in that situation. If yes, and if the difference is perceived by other actors, the entity is an actor in that situation. As a means of following nonhuman actors I traced them across documentary and interview data, but I also engaged in 'body-work' (Myers, 2008, 2012) in the UK lab where I conducted part of my fieldwork. I was delegated some basic lab work within the scientific lab that was the focus of fieldwork, which enabled my direct engagement with nonhuman actors. Instead of solely relying on the descriptions by scientists and my observations of situations as a form of knowing, my body-work enabled different ways of knowing the world I was mapping. It put the principle of symmetry to use in practice. While the combination of body-work and more conventional ways of seeing allowed for different ways of knowing and thinking about the field, there were times when the field constrained what it was possible for me to know, how and to what extent I could follow the actors in physical settings. I will discuss some of the issues stemming from these limitations further below in sections 3.3 and 3.8.

In this chapter, then, I will explore some of the practicalities of fieldwork and some of my field experiences. I will not detail every aspect of those experiences. Nor will I provide a fully comparative account of the experiences in the UK and Finland. Rather, I will pick out and illuminate instances of analytical and experiental significance. I will, however, begin with a discussion of some methodological tools I develop in this thesis and through which I managed the comparative aspect of this project.

3.1 A comparative methodology

This is a comparative study. How the trajectories of the UK and Finnish GD projects have become so different is an overarching concern of this thesis. As cases for comparison, the Finnish and UK GD projects align with Sheila Jasanoff's criteria of being "different enough to present interesting contrasts, yet similar enough for the variations to be disciplined" (Jasanoff, 2005: 29). Although it is unclear what will happen after the UK's departure from the European Union, the two GD projects continue to operate within the same policy framework laid out by the 2011 EU Directive on the long-term management of nuclear waste, for now. The framework is supported by an international consensus that predates the Directive by decades and holds GD as the best available option for the long-term management of nuclear waste. On a country level the Finnish GD project is currently one of the most advanced in the world, while the UK's project has been stumbling for decades. In line with

Jasanoff's criteria, we can surmise that the UK and Finnish GD projects offer fertile ground for a comparative study.

Disposal cultures

Explicitly pointing to the difference between the two projects at this point might appear to be at odds with what I am going to discuss below: differences as a relational effect of particular and situated sociomaterial doings. During an interview one of my participants voiced concerns over the comparative aspect of my study.

> Each country is different. They cannot be compared to each other or any other country. So, please don't fall into the trap, we read this all the time, that 'oh, Finland has done this and other countries, they cannot do it, because this and that'. Every country has it's own thing, story, history.

What emerges from her concern is an interpretation of difference as an explanatory category. In that interpretation, historical and cultural differences explain the differing progress of national GD projects. From that perspective, a comparative study of GD projects can be seen as unproductive and offering little new knowledge. Where the participant above saw cultural considerations as prohibitive of comparison, other participant scientists and engineers sought to explain Finnish 'success' and UK stumbles through material differences such as the comparative scale and complexity of nuclear waste inventories or existing nuclear infrastructures. What I will posit in this thesis is that *all* of these are effects of different sociomaterial doings that are accomplished by *disposal cultures*. Neither material nor cultural differences can categorically explain successes or stumbles in the implementation of GD, so an alternate approach needed to be developed.

The imagination of *disposal cultures* draws on Karen Knorr Cetina's conceptualisation of epistemic cultures. She describes epistemic cultures as "amalgams of arrangements and mechanisms – bonded through affinity, necessity and historical coincidence – which, in a given field, make up *how we know what we know*" (Knorr Cetina, 1999: 1, emphasis in the original).

Epistemic cultures have their own sociomaterial realities. How they create knowledge emerges from situated arrangements and mechanisms. Similarly, disposal cultures are situated compositions and composers of particular forms of knowledge and knowing in the nuclear waste realm. As effects of particular sociomaterial entanglements, disposal cultures have no explanatory power. As such, exploring GD future making through the lens of disposal cultures enables the researcher to focus on situated practices of knowledge and future making, instead of using national differences as explanatory categories.

Diffraction

As a relational analytical device, disposal cultures have an inbuilt diffractionist sensitivity. Diffraction does not give explanatory power to difference. Instead of beginning any analysis from differences, diffraction charts how the effects of difference emerge through entanglements and situated doings. In the world of physics, diffraction describes a physical phenomenon that is unique to wave behaviour. It refers to the way in which waves 'bend' when they encounter an obstacle, and how waves 'combine' when they overlap. A familiar everyday example of diffraction is the overlapping of ripples when a stone has been dropped into still water. Donna Haraway, in her own words, 'invented' diffraction as a semantic trope in its sociological use to "record the history of interaction, interference, reinforcement and difference" (Haraway, 1997: 14, 273). Diffraction "attends to the relational nature of difference; it does not figure difference as either matter of essence or inconsequential" (Barad, 2007: 72). Diffraction is a departure from the more reflective approach to comparative studies. Reflexivity, as an optical metaphor and mostly used in discussions on researchers' ethical and analytical sensitivities, presumes difference. It establishes difference between the researcher and the researched, between cultures and practices as a starting point to comparison. While reflective accounts take differences into account, they do not (necessarily) map the emergence of difference. Therefore, rather than using the UK and Finland as mirrors to each other to reflect on their similarities and differences, I turn to the metaphor of diffraction as a comparative tool. Drawing on Haraway and the philosopher-physicist Nils Bohr, Karen Barad (2007) posits that diffraction is both an object and a method of exploration:

> At times diffraction phenomena will be an object of investigation and at other times it will serve as an apparatus of investigation, it cannot serve both purposes simultaneously since they are mutually exclusive. (Barad, 2007: 75)

So, in the first instance I mapped diffractive practices in the lab and beyond in both cases. I traced how differences between safe and unsafe, success and failure, wastes and assets were made. In the second instance I brought the two case studies into conversation with each other to trace the spaces where the effects of these makings of difference emerged, and to explore whether those points of emergence overlapped or diverged between the two cases. The aim here has been to analyse the disposal cultures together-apart (Barad, 2007); to set them in a conversation rather than comparison with each other. Thus, rather than a mere 'traditional' reflective comparative study, the approach I take here can be classed as 'comparative-conversationalist'.

In the following two sections, I describe my core fieldsites in the UK and Finland; the 'benefits' of undertaking multi-sited ethnography, and my experiences of some of the issues around negotiating access to fieldsites.

3.2 Multi-sited ethnography

In a sense, this study is by definition a multi-sited ethnography (Marcus, 1995b). It is a 'comparative-conversationalist' study with two university research labs forming the core sites of an ethnographic investigation. Overall, I spent a year doing fieldwork. I spent the period from February 2015 to July 2015 in the UK, and a period from August 2015 to March 2016 in Finland. During the year I conducted interviews with central figures in the respective disposal cultures and did participant-observation in the research labs.

Labs

In the UK lab, the research group had around 60 members at any one point including staff, PhD students and visiting researchers. The group occupied two floors at the top of a 13-storey building, but flowed beyond its designated space. The PhD students in the group shared an office space where I was given a desk next to my participants. From the PhD office two doors led to a corridor that was aligned with the offices of the academic staff, a printing room and a small kitchen space. The lab space was two floors above the offices and was divided into eight different sections. This floor also had a number of postdoctoral offices. Each of the lab sections was designed and designated to particular types of work from sample preparation, to analytical work, to work on cement materials and work on radioactive materials. The lab included a national facility with state-of-the-art instruments available for visiting researchers working with radioactive materials. Access to the lab spaces, however, depended on group membership. The lab operated a closed access policy, which meant that the lab could only accessed with an authorised staff or student card. This imposed some restrictions and demands on me as an ethnographer, which I will discuss further in sections 3.5 and 3.7. Aside from the marked office and lab spaces, the group had access to departmental labs shared by other research groups and that were scattered around the building. Some of these labs housed instruments the group did not have, such as abrasive cutters, glass melting furnaces and pycnometers to measure the density of materials. Others homed instruments, such as welding equipment and the Hot Isostatic Press (HIP), the group could not house in its own labs. Others yet housed instruments, such X-Ray Diffractometers (XRD), the group had, but could resort to if the group's own instruments malfunctioned or were fully booked.

In Finland the research group occupied two floors. The actual labs were in the basement below the office floors. The biggest lab was a huge space with an industrial feel to it. This was where all the big machines for welding and otherwise lived. When I initially visited the lab in March 2015, months before my fieldwork, the space was under refurbishment and some of the machines stayed offline for most of my stay. The basement also housed a number of smaller labs with a range of analytical instruments, such as the Scanning Electron Microscope (SEM) I recognised from my time in the UK lab. I was whisked through these locked spaces accessible with a staff key with a semi-jogging pace during my initial visit, but did not re-enter them during the actual fieldwork phase for reasons I will discuss in section 3.6. The offices were in the first floor. The offices of the academic staff, and a small library that coupled as the office of the group's administrative person, were situated on the right hand side of a long windowless corridor. From the white walls to the nondescript wall clock the place had the feel of a generic Finnish educational institution. At one end of the corridor were a small kitchen and a seminar room, where the senior academic staff held their weekly Monday meetings. At the opposite end were two offices shared by research assistants and PhD students. Together these offices housed about 15 people, including me. Altogether the group consisted of around 40 people, mostly male members of the research and academic staff. Unlike in the UK, PhD students here were a minority.

The cellularity of both of these fieldsites, the multiple spaces that composed these labs, raises questions about how we define and bind our sites. In neither case, were the sites simple or singular spaces with clearly defined boundaries. Work, *some* materials and scientists flowed between different spaces freely, if not thoughtlessly. In the UK lab, restricted access and the presences of hazardous materials in the lab required particular rituals before boundaries were crossed. Mundane actions of checking that one had their swipe card upon entering the lab, donning a lab coat immediately after entering, and washing hands prior to leaving the lab performed the boundary between lab and office spaces. Even in Finland keys were required to access the office and lab spaces. Yet the 'lab' becomes an umbrella term encompassing a multitude of sites and spaces within the 'site'.

Moving between sites

While the sites in a way were multiple in themselves, Christine Hine (2007) notes that a simple comparison between two labs does not capture the spirit of multi-sited ethnography. She notes that such lab-to-lab comparisons tend to be founded on given notions of the sites. They assume that labs are distinct sites containing culturally significant wholes. Such a straightforward imagination of 'multi-sited', Hine goes on to argue, fails to acknowledge the ethnographer's role in composing those sites, but also the notion that lives are "lived not in discrete locations, but through various forms of connection and circulation" (Hine, 2007: 656). Hine's critique is laid out particularly against early lab ethnographies. While these studies developed our understanding of scientific knowledge production, they tend to cease their analysis and description at the lab door (e.g. Latour and Woolgar, 1979 (1986); Traweek, 1988). Already in

1983 Bruno Latour, nonetheless, asserted that if we accept that scientific knowledge production is an ordinary social practice, we should move beyond the lab walls to trace how science is assigned its epistemological speciality:

> sociologists of scientific practice should avoid being shy and sticking only to the level of the laboratory (for this level does not exist) and being proud of diving inside laboratory walls, because laboratories are the places where the inside/outside relations are reversed. In other words, since laboratory practices lead us constantly inside/outside and upside/down, we should be faithful to our field and follow our objects through all their transformations. (Latour, 1983: 160)

Where Latour made his point through engaging with historical materials rather than ethnographic experience, contemporary STS accounts tend to follow Latour's proposition and operate across a broader definition and range of field sites.

In line with the call to follow actors discussed at the beginning of this chapter and Latour's call to extend our investigations beyond the physically defined lab, George Marcus suggests that 'following people, things, metaphors, plots, biographies and conflicts' (Marcus, 1995b: 106–110) brings objects to the heart of multi-sited ethnography. Research objects, rather than research sites gain the centre stage in multi-sited ethnography. Travelling between sites, Knorr Cetina (1999: 22) notes, "opens a window on the contradictions, discrepancies, variations and differences that divide settings". In this sense multi-sited ethnography enables us to map differences as they emerge within and between disposal cultures. Knorr Cetina's own sites were labs specialised in particle physics and molecular biology, yet Anne Beaulieu (2010) encourages more creativity in the way we might define our sites. She notes how STS is increasingly moving away from physically bounded sites to excavate forms of knowledge production where physical spaces are less central. She flags online forums as such non-spatially defined spaces of knowledge production. Both research labs I engaged with extended from the physical lab and offices to digital spaces in the form of mailing lists that were used to communicate relevant events, news and so on. Multiple sites, thus, need not be at different physical locations. The strength of multi-sited ethnography stems from a rejection of physical boundaries and a willingness to follow actors to a range of spaces.

Thinking innovatively about our field sites enables us to compose our own fields through the research process (Hine, 2007). My field transcended the lab to include websites, documents, email interactions, meetings, lectures, seminars, conference venues, and cafés. Following the actors kept the field lively. It led me beyond the immediate versions of the field I had come to envision. In that sense multi-sited ethnography is risky. It demands openness from the researcher. Following the actors led me to a meeting on the development of deep borehole disposal as a complimentary method to GD. It took me to an international Implementing Geological Disposal Technology Platform (IGD-TP) meeting where I presented my work. It took me to Chernobyl alongside the scientists I worked with in the lab. It took me to a two-day *Introduction to the Nuclear Industry* course organised by the National Nuclear Laboratory in West Cumbria, and to a low-level waste repository in Gyeongju, South Korea. While all these travails are not included in this thesis, following the actors led to instances of intra-action and engagement with various scientists and sites I could not foresee at the start of this study. Nonetheless, when things were not 'working out' during my fieldwork, I hanged myself on the idea that I was doing a traditional spatially defined lab ethnography. The most notable consequence of this was that the narrow view I had of the field in the first instance did not reflect the work I was doing. Additionally, when my fieldwork in the lab was not progressing as I had hoped, my sense of the project's manageability eroded. I will discuss on this in section 3.7.

3.3 Negotiating access

As I mentioned in the section above, I conducted half of my fieldwork in the UK (February 2015-August 2016) and half of it in Finland (September 2015-March 2016). I came away with two very different field experiences that I will describe in the following five sections. I have come to view these differences through the metaphor of doors and walls. In a 1988 paper Latour as Jim Johnson considered the door, a technical artefact, as an important social actor as follows:

> Walls are a nice invention, but if there were no holes in them, there would be no way to get in or out [...] So architects invented [...] a hole-wall, often called a *door* [...] instead of driving a hole through walls with a sledge hammer or a pick you simply gently push the door. (Johnson, 1988: 298, emphasis in the original)

For me the difference between walls and doors resonates with negotiating access to the field, but also with data collection. The absence of open doors and the presence of walls informed where, when and how I could collect data. The physical layout of the ‘field’ shaped my experience of doing fieldwork in particular ways, and I will discuss this more in depth in sections 3.6 and 3.7.

UK

In the UK negotiating access was as easy as gently pushing a door open to enter a space behind it. The leader of the lab where I hoped to conduct my fieldwork was my second supervisor. The lab focused on the design, manufacture and performance assessment of a range of materials envisioned to contain nuclear waste. Its overarching aim was to develop materials, processes and policy to support the clean up of the UK’s nuclear waste legacy. Although not certain, I felt fairly safe is assuming that my supervisor would grant me access to the lab. By the time I approached him, I had already had intermittent contact with the research group for a year. I had attended the group’s weekly meetings fairly regularly and presented my work at one such meeting. I had attended a three-day postgraduate winter school with the group and done two days of observations in the lab as part of my training in the spring of 2014. The group was aware of my existence, what sociologists of science do, and I was familiar with the group. When I approached my supervisor, he had two questions: when did I want to start, and would I like a tour of the refurbished labs. The tour, I was given immediately. I started my fieldwork the day after. However, the immediacy of the start was facilitated by my successful navigation of a series of bureaucratic hurdles (I will explore these in section 3.6) to the existence of which, I had been alerted to by a research fellow working in the lab.

Finland

To the UK's door, negotiating and maintaining access to the field in Finland at times felt as if pushing against the wall. First, securing a field site from distance proved more problematic. Familiarity was not on my side, as it had been in the UK, even where I thought it might be. While I was prepared for barriers[2], I failed to see the first one: language. Drafting an email to a professor, I discovered that I lacked the relevant vocabulary in my native language to communicate my research. After a number of re-drafts and grammatical and spell checks by my mother, I managed to draft a decent email. Additionally, having studied on a university level only in the UK, I had no experience of or contacts in Finnish academia. I had little initial idea who to approach, how to approach them, who could be helpful and/or interesting in terms of my research and where the most promising field sites might be. Little internet research answered most of these questions and I approached a professor running a lab I had identified as the most similar, (and thus in my mind, the most promising) to the lab in the UK. I received an apologetic 'no' from the professor as my planned fieldwork coincided precisely with the lab's planned maintenance and refurbishment. The second lab I approached initially welcomed me, but two weeks later rescinded their invitation.

Eventually, a mechanical engineering research group agreed to have me. Unlike in the UK lab, nuclear waste management and GD were not the group's research focus. Instead, important areas of research included the development of materials for a range of demanding applications, welding techniques and foundry engineering. It was not what I had envisioned, but my gatekeeper was welcoming and seemed cooperative. I had a chance to visit the lab in early

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[2] I knew to expect some challenges. This was partly because of the limited importance assigned to sociological nuclear waste research in Finland (SYKE, 2000). I had also been warned by an anthropologist[2] during an email exchange that gaining access to at least some actors might be difficult, and when I was already in the field an interviewee noted that the release of a documentary film critical of the GD project had soured some people's attitudes towards 'outsiders' (Into Eternity, 2010).

spring of 2015 before starting my fieldwork to polish details and to discuss mutual expectations with regards to my stay. The plans seemed great including talks and seminars. My gatekeeper promised to take me along to a meeting abroad to introduce me to some people who might be relevant for my study. I left in March, and returned in the autumn, with high hopes that were fast to crumble upon my return, as I will describe in section 3.6.

In the following two sections I will first illuminate my approach to participant-observation and second, how the field imposed certain demands on me, and partially assigned roles for me.

3.4 Participant observation or ‘body-work’

“If construction is wrapped in bounded locales, the ethnographer needs to “penetrate the spaces” and the stream or practices from which fact construction arises” (Knorr Cetina, 1995: 151). To penetrate the spaces and stream of practices in the lab, I wanted to *really* participate in those practices. Mere observation, I felt, would not be enough to really know the field. I was lucky enough that in the UK lab my supervisor offered me the chance to get my hands dirty ‘doing some science’, before I had a chance to ask about actively participating in the life of the lab.

Natasha Myers (2008, 2012) notes that life scientists make sense of molecular forms and functions through *body-work*. The body, she holds, has a central role in learning, relaying and interpreting the specificities of molecular models. She proposes that by twisting their bodies to mimic molecular models, scientists use their bodies to generate new forms of knowing and things that are known. If performative body-work is a means of sense-making in natural sciences, why not in ethnographic investigations? John Law (2004) has posited that if we want to know the messes of ‘reality’, we need to teach ourselves know those messes and realities by using unusual methods. We need to create new ways and forms of knowing. Body-work for me stands as an idiom for my participation in the life of the lab. As I became a ‘trainee scientist’ (as one of my participants labelled me), body-work as a tool of ethnographic sense-making added new forms of knowing. It generated data I could not have produced by simple

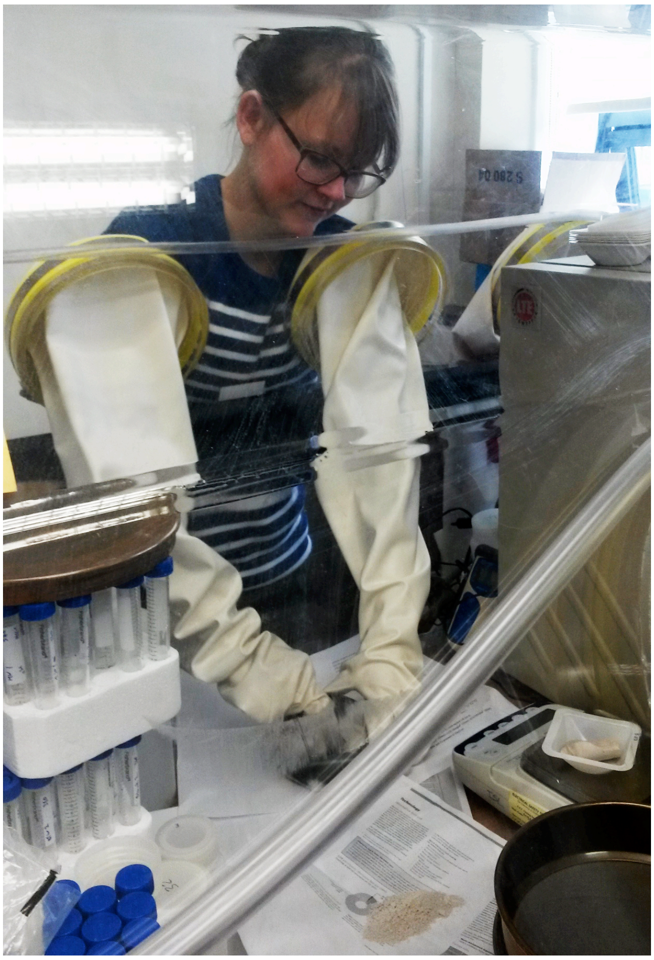

Figure 5. Doing body-work: grinding cement with a pestle and mortar in a glove box.

observation. How I came to know, and what I came to know, was not separate from how I was in the lab. Watching someone being frustrated by a planetary mill is entirely different from becoming frustrated by the mill. Listening to someone complain how crushing cement is hard work is utterly different from feeling the pain in your back or the bruise in your palm for having crushed cement for three hours.

Body-work, thus, opened up new ways of knowing and following the actors. I came to generate data through bodily engagements and encounters that were more complex and nuanced than if I had just relied on hearing and vision. I could feel the actors, their cooperation and resistance under my fingertips. Not only could I follow the actors in the lab, I became part of the motor behind their movement. While body-work expanded what it was possible for me to feel, hear, imagine, see and say in and about the field, it also helped to maintain curiosity and analytical sensitivity towards the routines of lab life, as I will elaborate further below. Putting on a lab coat or brushing glass-ceramic powder through a sieve with a paintbrush always felt awkward regardless of how many times I repeated the acts. In part then by performing my role as a 'trainee scientist' through sociologically sensitive body-work I never reached the "comfortable sense of being 'at home'" Paul Atkinson and Martin Hammersley posit as a danger signal for any ethnographic work (Atkinson and Hammersley, 2007: 90). 'Going native' for them is a cardinal sin in ethnographic work as, in their reading, it leads to the blunting of the analytical and critical edge and lessens the intellectual distance with which ethnographers enter their fields. Nonetheless, I had to take steps towards 'native-ness' as a prerequisite for body-work and maintaining any kind of presence in the field. My skills as a sociologist of science were irrelevant in the lab environment. In order to do sociological research in the lab I had to, in a sense, become more like a scientist.

3.5 To study one you have to be one?

As a sociologist of science, my skills in the lab were of little use. As a prerequisite for the body-work I described above, I had to acquire sensitivities and practices that were more relevant to the lab than my existing set of skills. The ease with which the door to the lab in the UK opened was conditional on my successful completion of basic training and lab inductions. All newcomers had to go through the same process to have access to the lab, and in this sense I was no different from the scientists working in the lab.

A research fellow sent me a list of online Health and Safety training modules that were the precondition to my entrance and maintained presence in the lab. The list included five modules and a final exam[3]. Each of the modules consisted of a video followed by a multiple-choice quiz at the end. The training took about two hours to complete. It covered matters such as background radiation, what ionising radiations are, the effects of radiation, dose limits, units of measurement, legislation, administrative and enforcement procedures and the control of the hazards from working with the common radionuclides used in the lab. At successful completion, I received a downloadable certificate for each

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[3] The modules included fire training, Introduction to Radiation Protection; Effects, Limits and Legislation; and Control of Hazards - Unsealed source work.

module. I had to present these as proof of my eligibility for lab access in the lab. The training and the certificates demonstrated that I was equipped with sufficient knowledge of how to be and act in a radiation lab. The training did not, however, provide me with practical skills or knowledge about the lab I was entering. On top of the online training, I went through three separate lab inductions that all covered specific workspaces in the lab. These were the spaces where my participants mostly conducted their work. The inductions did not involve training on lab instruments but were 'common sense' introductions to the spaces and their particularities. None of this diverged from normal practices. Only with with regards to filling and filing Control of Substances Hazardous to Health (CoSHH)[4] and risk assessment documents my status as a sociologist and the reason for my presence in the lab were taken into account. These documents were another prerequisite for lab work. Scientists had to fill them for all materials and processes (i.e. sample preparation, conducting experiments and so on) they envisioned as part of their research. The documents were reviewed by the relevant academic and departmental health and safety staff. Since I was not expected to conduct my own experiments (although this idea had been floated by the group leader), I 'got away' by studying my participants' forms, signing them and acquiring the necessary signatures for the documents. Before entering the lab I was also given a Laboratory Induction Manual to study. It was a 20-page document that outlined general laboratory rules and code of conduct from caring for the lab spaces and instruments to protocols for data recording and storage onto proper lab attire.

Playing the part

Apart from relevant knowledge about lab life disseminated through training and the manual, the field disciplined me towards a more scientist-like existence in the lab by other means. The field governed what I wore, how I opened doors, how I moved around, how I stood. The starting assumption in the lab was that 'all surfaces are at least slightly contaminated' (field notes 11 February 2015). This assumption translated into routine-like removal of protective gloves before opening doors, hand washing before exiting the lab, but it also reverberated in

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[4] COSHH is a UK law requiring employers to control substances that are hazardous to health.

how the scientists carried themselves in the lab. After I had spent some time in the lab observing the scientists at work: their movements, ways of being and engaging with the lab space I became aware that I was differently. This difference I surmised arose from differences in our awareness of contamination, risks and hazards. The way I was in the lab constituted health and safety risks in the lab. I had bad office habits – such as resting my chin or cheek on my hand, leaning against walls, over desks, in effect slouching – I had to identify and unlearn to ensure that I did not unnecessarily come into contact with hazardous materials.

What I, and the scientists, wore to the lab was governed by lab rules. Skirts, dresses, shorts, and open shoes were definitely forbidden. They exposed skin and constituted a health and safety risk in the lab that routinely dealt with hazardous and toxic materials. Lab coat, safety glasses and gloves were compulsory. While it made me look the part, the lab coat underlined my difference in the lab.

Figure 6. Lab coats hanging in the lab.

> My lab coat is massive. It’s not mine. It’s borrowed, like always, but for the first time it makes me really uncomfortable. What if these huge clown-sized sleeves are going to get in the way of sample prep? (field notes 9 March 2015)

Donning the white coat, looking like a scientist while not being one, became a constant reminder of the contingencies of my access to the lab. My presence, and the availability of a lab coat, always depended on someone else’s (temporary) absence from the lab.

On an experiental level, the lab coat created diffractive moments. Wearing a lab coat marked me, in my eyes, as somewhat-same-but-different. The coat, as much as the training, was my licence to the lab, but it could be taken away at any point. Thus, while the coat created equivalence between the scientists and I, it also marked difference. What for the scientists were routine, almost unconscious, sociomaterial practices, such as putting on the coat, were much more momentous for me. They allowed access, created equivalence and my difference from and in the world I studied, even when I became embedded in that world.

Shifting roles

As a participant, I was more an extra pair of hands than a brain in the lab. The work I was delegated was something most people could have done. I was trained on two instruments (a balance and a planetary mill) necessary for the preparation of glass-ceramic samples. The training I received was basic, but sufficient for the job I had to do. My main task was to weigh and assemble glass-ceramic powders from ‘raw ingredients’ and sieve the assembled mixture to ensure an even grain size of the powdery samples. After this the powders were placed into small welded cans that underwent a high pressure, high temperature treatment in the HIP to ‘melt’ them into a solid glass-ceramic form. The now-solid sample would then go through a series of analytical tests to determine the characteristics and the suitability of the material for the containment of plutonium residues and other ‘orphan’ nuclear waste.

During this type of body-work, my relationship with my participants and the field was clear. I was a participant in their lab life in the same way as other scientists working in the lab were. I followed the same rules, dressed the same, and followed the same steps as anyone else preparing a similar sample would have done. Nonetheless, sample preparation as body-work was also a tool of observation. Through body-work I was able to directly engage with a different set of actors. My experiences of the materials and instruments in the lab were not mediated by the scientists. Rather, through body-work I was following, feeling, experiencing and embodying different relationships in the field. I was able to build my own experiences of and relationships with the nonhuman entities in the field. The hybridity of my presence, my role as a 'trainee scientists' / participant-observer blurred the boundary between the participant and the observer. These roles were situated and shifting, oftentimes simultaneous and overlapping. Similarly the observer-observed relationship with my participants was fluid and situated.

> Jodie explains to me that she and David do their pH measurements in different ways. He has left instructions for her, which she now follows. "I do this differently, and I will explain why when we get there", she concludes and works in silence for a while, before asking me "would you write down as much as stuff if I was silent?" (field notes 19 May 2015)

Here, the roles between the observer and observed were not predetermined. They were blurry, situated sociomaterial performances. In the first instance, Jodie performed her role as the observed by describing the work she was engaging with and explaining what she was doing. The silence following the description gave me the space to write down notes (to perform the observer role), while the act of writing down notes subsequently prompted her to ask me questions about my methods (performing her as the observer and me as the observed).

The example above also describes how as ethnographers we cannot always choose our roles in the field (Balmer et al., 2015; 2016). Sometimes our roles are assumed or assigned to us by our participants. In their collaborations with scientists and engineers in synthetic biology Balmer et al. (2015) identified a number of roles assigned to them by their collaborators. Each of these roles carried its own assumptions about the type of activities and interests social scientists bring to and engage with in their entanglements with synthetic biology. Balmer et al. note how “various positions and actions become differentially possible across space, types of engagement and over time” (ibid., 16), highlighting the situatedness of the roles and research we can perform in our engagements with the field.

My own role flowed between the extremes and my experiences of being a ‘nuisance with a notebook’ and a ‘helping hand’. These abstractions were not intimately linked with the role I had been assigned or had adopted at any given point. When I was more an observer than a participant, I was imagined both as a stalker (nuisance) and as a secretary (help).

> Alex and I are heading to a lab to drill holes to her iron lids and a technician walks up behind us.
> Alex: “It feels like you’re lurking behind us!”
> Technician: “I’m your stalker!”
> Alex: “I don’t need you. I already have one.” [i.e. me]
> Technician: “Ah, so you do!” (field notes 7 April 2015)
>
> Alex asks me if I could lend her a piece of paper, so I tear off a page from my notebook and hand it to her. She folds it and uses it to pour her sample back into its bag.
> Alex: “Could you take this down for me: 1.0914?”
> “1.0914,” I repeat out loud and write down the number, the weight of her sample in grams, in my notebook. (field notes 4 March 2015)

The examples above highlight the contingency of my roles and how my participants assumed and performed my roles in particular ways in the field. At other instances, negotiations of my role were more explicit, as when Jodie asked; “So, what’s your role today? Are you an observer or a helper?” (field notes 28 April 2015). At yet other instances, the negotiations were more implicit actions such as ‘sliding into the gloves’ of a glovebox or helping to carry things from one lab to another. Or they could be offhanded remarks made by the scientists that alerted me to my role in the lab.

> The sample prep goes uneventfully until I spill some powder on the bench top. “Oh, bloody hell!” I shout inside my respirator in annoyance.
> “Oh, it’s fine. Don’t be too harsh on yourself. You can’t be perfect yet. You are but a trainee scientist, Marika,” Jodie, who is in the lab, remarks.
> “Mm.”
> “But I know the feeling. It’s horrible; messing up someone else’s sample.”
> (field notes 7 April 2015)

Doing ‘body-work’ expanded the ways in which it was possible for me to be in the field, what kind of entanglements emerged and how I could do my research and maintain research relationships with my participants and vice versa. Body-work, ‘getting my hands dirty’, created a measure of equivalence between my participants and I. Although ‘less than’ a scientist, I was ‘more than’ a sociologist. Body-work enabled the sharing of common experiences from ‘messing up samples’ to the difficulty of estimating the volume to mass relation of materials, to engaging with instruments for the first time. Doing, rather than just watching, established a measure of familiarity with the scientists in the lab. In a limited way we could share experiences about lab work, while the shifting and situated roles allowed mutual questioning, creating a measure of equivalence between the scientists and I.

3.6 Absent presence

When I entered the field in Finland things had changed drastically from my initial visit to the lab nearly six months earlier. I was still welcomed to the lab, but was immediately told that my gatekeeper would be absent from the field for nearly the whole duration of my fieldwork due to unexpected circumstances. The absence of my gatekeeper turned out to impact my fieldwork much more than I imagined and in ways I did not anticipate. His absence lunged me into an epistemological crisis mode. It informed the data I could generate; how I saw data; how I experienced the manageability of my fieldwork; how I came to conceptualise the field; and how I imagined fieldwork successes and failures. I will discuss these matters here as well as in section 3.7.

My field experiences in Finland became increasingly defined by what I regard as *absent presence*. The original plan, agreed with my gatekeeper and his PhD student Tom, was to follow Tom's project in a similar way I had followed the two projects in the UK. The overarching aim of the project was to explore the microstructure and deformation mechanisms of copper canister welds. In its detail, the project was much less structured and its objectives more loosely articulated than those of the well-defined and bounded projects I followed in the UK. This came to be increasingly problematic for my participant as well as for my project. When I was beginning my fieldwork in Finland, Tom, about a year into his PhD, had not yet begun to work on his PhD project. Instead he was finishing up a project he had inherited from another researcher who had already left the lab and beginning to write a paper on the project. The exact focus of Tom's own project was meant to be clarified later in the autumn in a meeting between him, his supervisor and external collaborators. Tom assured me there *would* be a project to follow after the meeting, implying there would be little for me to observe in the mean time. The meeting was a disappointment to him. The project had not gained any more clarity. By February, towards the end of my fieldwork, the situation had not changed significantly. Tom led a fairly aimless existence in the office. He was waiting for a meeting with his supervisor to discuss which of the four potential foci his supervisor had identified for the project he would focus on. Tom suspected that his preferred choice would not align with the preference of his supervisor. While he had much more space to negotiate the focus of his project than his colleagues in the UK did, he was anticipating some tension and noted "issues might emerge if [my supervisor] decides to push for his preferred alternative" (field notes 9 February 2016). By this point I too was becoming increasingly fatigued and annoyed by the situation. The longer the situation dragged on the less I saw of my increasingly frustrated participant.

> Ended up observing nothing. This … is annoying. (field notes 21 January 2016)

I began to despair over my project. I was struggling with balancing my expectations and what was (not) happening in the field. Similarly I had difficulties negotiating my presence in the field. Maintaining my presence in the field was a challenge in any case, as I will discuss in section 3.7. Now, I was struggling with managing my felt *need to do and see something*, while sympathising with Tom's plight and respecting his right to withdraw form the project, as was outlined in the consent form (see Appendix I) I had given him upon entering the field and that we both had signed.

Already in November I had moaned at my supervisor about having *no data*. Her enthusiastic remarks that no data *was* data fell on deaf ears. All I saw was a thesis devouring black hole in my set of data that would embarrass me and everyone else involved with the project. Feelings of helplessness and detachment began to creep in. Ironically, I had had a similar conversation about the nature of data with Alex in the UK lab. She had similarly struggled with the relationship between data and failure.

> Alex hasn't recorded many results of the experiments where her cans had failed. She notes how it has taken her some time to understand that a failed can is still a result, and that something can be drawn from it. (field notes 22 April 2015)

It was much easier to see the sense in the notion that no data *was* data when it was someone else's project. Instead of contemplating what I was observing by 'seeing nothing', I was preoccupied with absence of the type of data I had wanted and expected to generate. What I also missed at the time was the similarity between my and Alex's struggles to conceptualise usable and useful data. Neither did I detect the emerging opportunity to reiterate the classic STS wisdom of science as a normal social practice where data and things worth pursuing were negotiated, where things beyond the lab affected and shaped what happened in the lab, what knowledge was or was not produced; where the momentary unraveling of the network of knowledge production led to absent presence.

3.7 Present absence

Challenges I experienced with data generation were not limited to the confined observations I was able to make in the lab in Finland. A lack of shared space made my interactions with Tom dependent on coordination and explicit decision-making rather than flexibility and spontaneity. Where metaphorical walls had in ways funneled my entrance to field in Finland, physical walls imposed a practical problem once I was in the field. I regard this problem in terms of *present absence*. As I mentioned in section 3.5 I was given a desk space in one of the research offices. This, however, was not the one where Tom worked. Despite attempts to maintain constant presence in the field, I found it increasingly difficult to do this in a meaningful way that was comfortable both for me and Tom. I spent a significant amount of time in the office, but failed to 'normalise' my presence during my six-month stay. As a researcher, I found the walls between our offices increasingly problematic as time wore on. They played a key part in the relationship that was slowly emerging and taking shape between me, Tom and the field as a physical space. They made me feel out of control of my project. Confining me in the office next door, they allowed Tom to create my absence even when I was present. As he had no clear project plan, I partly relied on him to inform me when 'things started to happen.' He admitted that when things started to happen he forgot about my presence. I grew increasingly frustrated. I could not just hover over his desk hoping that serendipitously something would happen. I was at a loss on how to shift my present absence to present presence.

In both the UK and Finnish lab my participants had notable handle on what they allowed me to see, what they showed me, how they performed their research for me. Their performances informed what I could say and know about the field. Latour and Woolgar (1986 [1979]: 48) have described the desk as the "hub of [the] productive unit" in the production of scientific knowledge, yet my participants performed this productive unit as unobservable. In the UK lab they were happy to narrate and allow me to follow their lab work, yet the actual sense-making process at the desk emerged as an internalised, quiet and private work. I could trace the whole sequence of sociomaterial production of inscriptions, and the evolution of sample materials into graphs, numbers and images, through the various stages and spaces in the lab, as I was part of the process. Yet these inscriptions vanished from my field of vision once they reached the desks of my participants where they would be translated into knowledge claims. In the UK lab, my participants were keen to present me only with what they considered ‘interesting’. The boundary between ‘interesting’ and ‘uninteresting’ roughly followed the boundary between lab and office spaces. Although some lab work, mainly some aspects of sample preparation were described as ‘so boring’ by the scientists, they were seen as an important and interesting enough for me to observe *and* participate in. I was an audience to lab work, but I was not privy to the details of what happened backstage at the desk. The privacy of deskwork was the norm. Where the lab was an active space, the office was calmer. Discussions were fewer and hushed, and people did not frequent each other’s desks. My snooping over someone’s shoulder in the office would have constituted a bigger disruption and disturbance than my presence in the lab did. The lab was a mobile space where people mingled, talked, worked and were trained. The flow within the lab made it a more benign setting for ethnographic observation and participation, while the rigidness of the office worked as a reminder of my limited capability as an ethnographer to control and determine the types of data I gather.

This absence of deskwork from the ‘observable’ was particularly problematic and frustrating in Finland. Tom was mostly based at his desk and performed his office as a non-observation space. Whatever he worked on at his desk, he deemed uninteresting – for me at least. Without fail he stopped working for the duration I spent in his office. I failed to establish the kind of friendly rapport with him I had managed with my UK participants. The lack of both familiarity and proximity topped with our shared stereotypical Finnish inability to engage in small talk maintained my excursions into his office on the side of the awkward and the artificial – more so than ‘necessary’ interactions in the field. Every time I entered Tom’s office I felt that I dragged in a bag of unspoken expectations; his expectations of his project, my expectations of his project, my expectations of my project and his expectations of my project, all jumbled up in a tense frustrating mess. More than in the UK, my interactions with him were always explicitly staged: we had roles to play. I as the observer and he as the observed. The less available he was, the plainer it was that I ventured into his space with clear motives. I wanted data. We were both aware of this. He knew that (aspects of) my data collection depended on his work. He knew I was as desperate to fill my notebook as he was to really start his project. As the situation stagnated, our roles became more and more entrenched. My presence in his space became too explicit, too staged. Both the physical and imagined walls grew in significance.

Even in the UK lab my movements and access had been contained by the lab's infrastructure. Because of the presence of radioactive materials in the lab, access to the lab was mediated by a swipe card system. Like a hinged door, the swipe card system allowed a "selection of what gets in and what gets out so as to locally increase order" (Johnson, 1988: 299). The completion of compulsory training should have led to the activation of the card I possessed. Although the matter was chased with the relevant people, my card was never activated and the lab door remained closed to me. Yet, my containment never became a barrier for accessing the lab. As a general rule, I only entered the lab with my participants who had functioning cards. If I needed to get in to prepare samples by myself someone would come and let me in. Moreover, since I shared an office space with my participants, transitioning between the office and the lab could be spontaneous

> Around 1:20pm, Jodie taps my shoulder. She's going upstairs to smash and sieve glass and asks if I'd want to tag along. (field notes 2 March 2015)

My presence in the PhD office allowed for opportunities for observation, to emerge unplanned. Ethnographic investigations could flow from one space to another fairly spontaneously. Somewhat counter-intuitively, the fluidity and 'surprise' in the field in the UK made me feel in control of my project. Conversely, in Finland the physical layout of the field prevented such spontaneity about when, what and whether to observe. Much more than in the UK, my research depended on Tom's definitions of the 'observable' and in some ways he was much more in control of what I could see and what not than I was.

3.8 Interviews

Alongside participant-observation in the labs, I conducted 26 semi-structured interviews (11 in the UK and 15 in Finland) with academics, PhD students, nuclear waste consultants and researchers, civil servants, representatives of implementing authorities, the nuclear industry, and regulatory bodies (see Appendix II for participant and interview information). My aim with the interviews was three-fold. In the first instance, they supplemented the observations I conducted in the lab. In Finland, where I used interviews to substitute for the relatively poor observational data I was able to produce. Conversely, in the UK I used interviews with academics, technicians and PhD students to clarify questions that rose during observations and to test my understanding of what was going on in the lab. Interviews in both the UK and Finnish labs enabled me to develop an image of what kinds of research and research problems individual researchers and the labs more broadly focused on – and how this research aligned with the priorities and central concerns of the broader disposal culture. In this sense, interviews in the lab allowed me to gage how the disposal project, the disposal culture and relationships therein were perceived in the labs, and how the researchers in the lab situated their work in relation to the broader disposal culture. Beyond the lab, I sought to map the UK and Finnish disposal cultures through the interviewing process. From initial documentary research I had identified a range of institutional actors and approached individuals within these institutions for interviews, while also being open to participants beyond the group of potential interviewees I had initially identified and sought to include additional interviewees from organisations flagged as important to the disposal project by my participants during interviews – which is how I ended up interviewing the regulator in Finland, but not in the UK, and an industry representative in the UK, but not in Finland.

The interviews, apart from one phone interview, were face-to-face encounters in places chosen by the interviewees. This meant that most of the interviews took place in the interviewees' offices, although two interviews took place in a café and one at an interviewee's home. The interviews varied between 18 minutes and 2 hour 20 minutes, but were on average approximately 50 minutes in length. The shortest one was the phone interview where I found it difficult to establish a friendly conversation and manage my participant's curt answers. Conversely, the longest interview stretched, as I did not have the heart or knowledge to stop my participant from talking.

The interview schedules (see Appendix III) I used in the process were thematically and fairly uniformly structured, although questions were adapted to participant's specific expertise. The schedules consisted of a set of 15 questions that I went through in the interviews. I did not stick to the structure of the schedule where following it could have disrupted the flow of the conversation. Where necessary or possible, I included probing and follow-up questions. I finished the interviews by asking whether the participants had any questions or points of clarification, which usually lead to a discussion of the PhD process, how I was going to handle the interview data and what was I going to do with it.

I recorded the interviews with my participants' consent. Before each interview, as upon entering the field for observations, I supplied my participants with an information sheet describing my project and a consent form. By signing the form, my participants indicated their willingness to take part in the interviews (or observations). Initially I used a dictophone to record interviews, but eventually transitioned to use my phone's audio recorder. While this put me at ease – the phone's recorder was easier to use, it was more reliable, and the phone's audio files were automatically compatible with the audio software on my laptop – a couple of participants voiced their suspicions about the phone. They expressed concerns that the interview recordings might end up on online social media platforms. Similar concerns were not raised in relation to the dictophone. However, going through the consent form, and underlining anonymity and confidentiality of the interviews promised in the forms, appeased the interviewees (an example interview schedule is in Appendix II).

In the following section, I explore how writing was an important part of the research and analytical processes; a way of thinking through my data and crystallising findings. I also discuss the messiness of translation, and mapping as a means to prolong the complexity of the field in the face of the orderliness created by the act of writing.

3.9 Writing and analysis

Writing is all over the ethnographic process. From taking and later typing up field notes to transcribing interviews and eventually writing a thesis, writing in various forms infiltrates every aspect of the research process. Writing is entangled with analysis. Even the monotonous and at times utterly slow and soul-destroying experience of transcribing is intimately analytical. Already during, or immediately after, transcription I highlighted interesting parts, annotated and coded transcripts. The same applied to my field notes. Listening to interviews, typing up transcripts and notes, and drafting thesis chapters are ways of thinking through data. Writing is a way of identifying absences, gaps and connections in the data, but also in our own arguments. Writing is a messy process with an ambition to create order. That process was rendered more complex by choosing to study two markedly different language contexts.

Translation

Writing is a means of translating our messy and entangled field experiences into an orderly form. Draft by draft our thinking should crystallise to a point where others can make sense of the world we are describing and be convinced by our description. Writing, then, is translation. Only by translating my experiences, notes and other forms of data into a single piece of writing, can I bring the world I mapped and the actors I followed to reach its intended audience.

Translation of data into descriptions, like translation from one language to another, assembles a collective through a language whose grammar, genre, idioms and tone are shared by the envisioned audience. Translation requires an acknowledgement that it is a process of creation, of making similar, but also of betrayal (Law, 1997). Translation transforms things into something that travels ‘better’. In the process messy field experiences become clear written descriptions. Mostly incomprehensible spoken Finnish is transformed into a more accessible English account. Operating bilingually was both a challenge and a benefit. Bilingual sensitivity to language and linguistic differences opened up ways of tracing and mapping discursive makings of long-term safety, and how these makings were entangled with imaginations of simplicity and complexity, matters of concern and matters of fact. Being able to compare written and oral English and Finnish accounts, but also English accounts written by Finns[5], enabled me to map nuances and intricacies in the situated performances of GD as a solution to the long-term management of nuclear waste. Conversely, trying to translate these nuances and intricacies, often emerging through idioms or other culturally situated expressions, was challenging. I was concerned about fostering nuances, I fretted over doing injustice to my participants' views and positions, and worried about staying loyal to their choices of words and expressions. This concern and sensitivity to language partly guided the choices how I present data in this thesis. I only translated the data I use in this thesis. As with the originally English data, I sought to treat this translated data with respect, appreciating its complexity, but also acknowledging that some things would necessarily be lost in translation. Translation, nonetheless, was necessary for making this thesis, in its entirety, accessible to audiences who have not suffered through years of Finnish lessons. Only through translations, was I able to bring Finnish experiences to be part of broader sociological conversations.

Translation, then, is boundary work. It performs new audiences and commentators. It joins cultures, performs inclusions and exclusions. It redraws boundaries for dissemination and discussion. Openly acknowledging the process of translation, be it from experience to description or from one language to another, and the decision making inherent in the process, works to remind the reader as well as the writer that all texts are drawn stories of the worlds we have carefully mapped.

Mapping

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[5] The vocabulary used in these tends to differ form the language used in accounts originally written in English.

‘Follow the actors’ is an implicit invitation to map. I began this project by drawing a list of actors I had identified as ‘central’ based on preliminary reading. In part this was a practical necessity. It was an exercise in identifying potential interviewees and actors to follow, and potential and potent questions to pose. Additionally, it constituted the first step towards making sense of the disposal cultures.

Mapping as a means of making sense of the world can be traced back centuries. More recently with the rise of digital methods, mapping has emerged in STS as a way of doing “digitally assisted ANT” (Munk and Jensen, 2014: 32). Cartography of controversies (Venturini, 2010, 2012), controversy mapping (Munk and Jensen, 2014) and issue mapping (Marres, 2015) trace actors in virtual spaces and produce visual explorations of the ways in which controversies unfold online. Having relied on the slower and more conventional of mapping through footwork, I have drawn here on historical mapping practices in European ethnology (Munk and Jensen, 2014) and situational mapping developed by Adele E. Clarke (2007) for non-virtual ethnographic work. Situational mapping that partly draws inspiration from Haraway’s notion of ‘situated knowledges’ (Haraway, 1991) and the historical-geographical cartography of European ethnology are sensitive to the complexities of the world they map. Situational mapping, as the name suggests, treats situations as its units of analysis. Clarke posits that no explanatory categories exist outside the situation: everything needed for analysis and description of a situation can be traced within it.

As analytical devices, maps (Figure 7) are relational living things. They evolve with the progression of the research and analytical process. A map “starts life as a single blank sheet of paper” (Tattersall et al., 2007). Mapping starts with simplicity, a list of actors and a blank paper. As the research progresses the map becomes messy with detail as the researcher traces and draws new links between actors. As such, maps are a poor aid to writing. They place established assumptions and explanatory categories at risk. Composed association by association, maps evolve, force to slow down analysis, and encourage the thinking through of data in creative ways. As a means for sense-making, maps

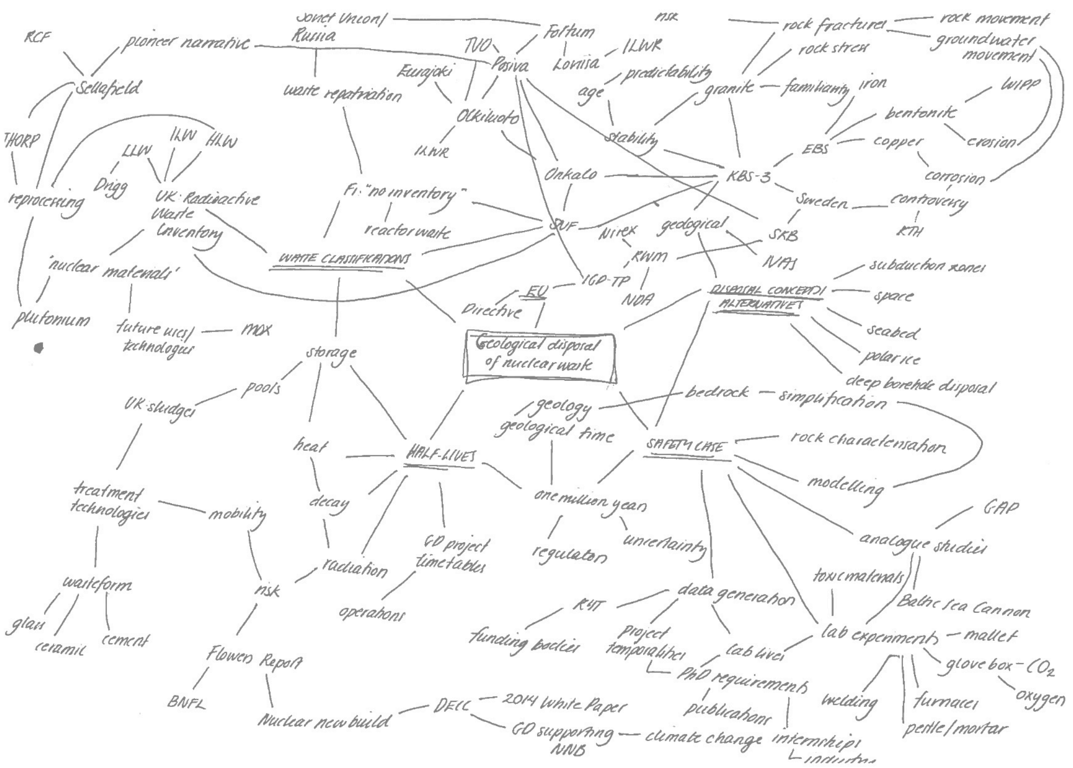

Figure 7. Situational map

can capture the messiness of a situation with more complexity than possibly more linear textual forms of analysis are able to do. Of course, even at their best maps are cleaned-up approximations of the worlds we study. Yet as analytical devices through which to think about data, maps are a means to linger with the trouble (Haraway, 2016) a while longer before the mess is by necessity cleared and cleaned into a PhD thesis.

3.10 Summary

This thesis is an effect of an effort of making a difference in the world; of an attempt to trace the intricacies of the making of very distant futures through GD. It is the effect of particular, carefully chosen research methods, of situated conversations, observations and specific sociomaterial intra-actions (Barad, 2007). In this chapter I introduced my take on diffraction as a methodological tools to explore the implementation of GD in a comparative setting. Diffraction is a relativist take on the world that explores the ways in which reality and differences are relational and emerge from specific, situated intra-actions between heterogeneous actors. The diffractive approach enables a conversation instead of comparison between the UK and Finland and avoids the trap of simplistic like-to-like comparison. I discussed the research process as messy, unpredictable, entangled, situated and negotiated, and elaborated on the challenges and opportunities I faced in the ‘field’ as a participant-observer. I discussed how my field sites, composed of people, instruments and infrastructures, performed me as an ethnographer, and my possibilities to know the field. They imposed demands on my knowledge and ‘way of being’ for access. Infrastructural constraints of the field rendered interactions with my Finnish participants in the lab and otherwise dependent on coordination and explicit decision-making rather than fluidity. This rigidness and lack of fluidity and surprise resulted in feelings of helplessness and uncontrollability of the project. Rather, it was the more unpredictable environment of the UK lab that made me feel in control of the research process.

To foster anonymity of my participants, I have renamed them after some of the voice actors from the Finnish children’s animation ‘Tales from Moominland’ (*Muumilaakson tarinoita*) and actors from the popular British sci-fi series Doctor Who.

In the following three chapters I describe the analysis and findings that emerged through the approach I have outlined here.

4 MAKING WASTE FUTURES

“On August 6, 1945, the Day of Hiroshima, a New Age began: the age in which at any given moment we have the power to transform any given place on our planet, and even our planet itself, into a Hiroshima” (Anders, 1962: 493). For Anders ‘the Day of Hiroshima’ marks the beginning of the Nuclear Age, a time where the future collapses into the present. In the Nuclear Age, the present has the capacity to transform itself as well as the future into a wasteland. The ‘inconceivably long aftermath’ (Piette, 2016) of nuclear activities, military or civilian, the past and the present implicate the future. Waste futures, which this chapter focuses on, are imagined and implemented as responses to nuclear pasts and presents.

In this chapter, I am concerned with these pasts and presents in the UK and Finland. I explore these times in order to map some of the ways in which nuclear wastes have been made and remade, and how these makings and remakings have affected the unfolding nuclear waste management challenge in the present and how they affect the anticipated future. In the first two sections of the chapter I will provide a brief overview of the nuclear infrastructures and waste inventories in the UK and Finland, while in the third section of the chapter I look at some of the challenges waste inventory reporting practices impose on making sense of the scale of the nuclear waste challenge in a comparative framework. In the following two sections I take a step back from the ‘nuclear nows’ in the UK and Finland to explore imaginations of nuclear waste trajectories in the UK and Finnish nuclear industries. In the final section of this chapter, I change pace entirely. Here I will draw on STS work on care, in particular on María Puig de la Bellacasa’s (2017) notion of ‘matters of care’, as a way of speculatively thinking-with the UK’s case how our infatuation with (rather than fear of) nuclear things has contributed to the unfolding of the nuclear waste challenge.

4.1 Nuclear places

Nuclear places in the UK and Finland are hugely different. These places echo the geopolitical situations in which the UK and Finnish nuclear industries were established, as I will explore below. A key difference emerges around spent nuclear fuel ontologies. The initial military push behind the UK nuclear industry necessitated the treatment of spent fuel as an asset providing plutonium for nuclear weapons. In the UK, then, the nuclear fuel cycle is open – meaning that spent fuel is reprocessed and recycled. In Finland, that never harboured any military ambitions, the fuel cycle is closed, and spent fuel is treated as waste. In practical terms this means that the Finnish nuclear infrastructure is simpler than its UK counterpart.

Geopolitical considerations further informed the designs of the UK and Finnish reactor fleets. Following the 1946 US McMahon Act, that forbade US nuclear cooperation with other countries, effectively excluded the UK from the Manhattan project. From this point on establishing an independent British nuclear deterrent was a national priority and the military imperative informed the choice of reactor design (Mackerron, 2012). Also in Finland reactor choices were driven by Cold War considerations. In a balancing act between the East and the West reactors were order from the Soviet Union and Sweden. In what follows, I will detail the existing nuclear infrastructure in the UK and Finland.

UK: From national priority to complexity

The UK has 35 nuclear sites, 30 of these have nuclear waste storages (Cairns, 2014; WNA, 2017a). Currently, the UK has 15 operational nuclear reactors: 14 Advanced Gas Cooled Reactor (AGR) and one Pressurised Water Reactor (PWR). The first reactor a Magnox prototype, at Calder Hall, was connected to the grid in 1956 making the UK the first commercial nuclear power producer and dating the beginning of the UK's civilian industry 21 years ahead of Finland. The historical backbone of the UK's nuclear fleet was formed by 26 Magnox reactors. All of these have been shutdown and some of them have been decommissioned. The UK fosters the most ambitious hopes for nuclear new build in Europe, albeit Brexit and Toshiba's financial troubles have shed some dark clouds over these nuclear hopes. With the entire AGR fleet to be taken off grid by 2030, the UK envisions the construction of at least three AP1000 reactors at Moorside in Cumbria, and two EPRs at Hinkley Point (ONR, 2017a, 2017b). Also ABWR (ONR, 2017c), Hualong HPR1000 (NAMRC, n.a.) designs, and the SMRs are under consideration.[6] The diversity of the proposed reactor designs has given rise to some concerns that the UK might be repeating past missteps by producing a diverse and a complex nuclear fleet. This could present challenges for the management of nuclear wastes from a diverse fleet as different reactor types produce different types of wastes (Rhodes, 2016).

As I mentioned above, the UK operates an open nuclear fuel cycle, although the government has announced a transition to a closed cycle in 2020. An open cycle is premised on the availability of reprocessing technology. THORP, the UK's reprocessing facility, is located at Sellafield, where the UK also stores 74% of its nuclear wastes. The implementation and life of THORP have been matters of great controversy, as the facility has never operated to its full capacity (Rhodes, 2016; Walker, 1999). Moreover, since THORP's main customers have been overseas, the UK now stores notable quantities of 'foreign wastes', which under contracts should be returned to the countries from which the spent nuclear fuel originally arrived for reprocessing. Walker (1999), however, notes that waste repatriations are unlikely. This further complicates the waste management situation in the UK.

Aside from reactors, storage and reprocessing facilities, the UK's nuclear infrastructure is composed of fuel manufacture facilities at Springfields, a uranium enrichment plant and related facilities at Capenhurst, and a low level waste repository (LLWR) near Drigg in West Cumbria. From fuel enrichment to energy generation, reprocessing and military applications, the UK nuclear industry has been self-sufficient, or some might say belligerent (Hill, 2013). The origins of the nuclear waste management challenge can be traced to the waste management practices of the past, while in part the present waste management situation has much to do with the complexity of the UK's nuclear fleet. William, a former member of CoRWM, reflected on the complexity of the UK fleet and noted how the "French-style approach" to nuclear engineering where "you could get one [reactor design] that would work and then just build a hundred of them

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[6] EPR= European Pressurised Water Reactor; ABWR = Advanced Boiling Water Reactor.

doesn't fit with the British psyche". Both the Magnox and AGR fleets lacked internal standards (Hill, 2013).

Figure 8. Nuclear places in the UK

The Magnox fleet initially served dual purposes, feeding both the UK military and civilian nuclear needs. From the first reactor connected to the grid at Calder Hall (1956) to the last one at Wylfa (1971), the power generation capacity of the Magnox was gradually increased ten-fold. The steady increase in capacity was accompanied by a steady evolution of the reactor design. As each station was a slight improvement to the previous one, each Magnox station was a one-off project, each slightly different from the others. The AGRs, still in operation, similarly are all unique on-site creations, each slightly different to the next. With each reactor design modified from the previous, "the British nuclear power industry", William held, "just killed itself with its own complexity". This complex commercial fleet was further accompanied by a breath-taking list of research, prototype and experimental reactors ranging from the Windscale Piles to the Dounreay Fast Breeder Reactor and from BEP0 to ZEPHYR.[7] Delving into the technical specificites and intricacies of each reactor type here is not meaningful for the purposes of the thesis. Important to note, however, is the diversity of these different reactor types. Matt, a Professor of Nuclear Materials, noted that the understanding of the scope and complexity of waste management has changed during the 21st century:

> What we probably understand now is that we are not going to be able to treat our radioactive waste legacy in a way that means that we've got a relatively small number of packages with a relatively small spread of properties. That's what we thought we were doing. (A Professor of Nuclear Materials, interview)

This diversity bears upon the present nuclear waste management effort. The diversity of wastes translates to diversity of containers, and Matt continued:

> Now it's pretty clear that the way we are going to have to treat the waste is going to produce quite a lot of packages. And these will all have unique behaviour, and actually if that behaviour is adequate, fit for purpose, that's not a problem. (Professor of Nuclear Materials, interview)

While the Matt only articulates the benefits of 'adequate' waste package behaviour, implied here is that an inadequate behaviour might be a problem. The diversity of waste packages creates an engineering, and by extension a safety, problem. The behaviour of the packages needs to be tailored to fit and complement, or at least not to undermine the behaviour of other packages, and their respective ability of contain waste. Diversity and complexity, thus, can be seen to exist in a conflicting relationship with the ability of the GDF to contain waste. Diversity of waste packaging fosters uncertainty about the compatibility of a broad range of behaviours particular to certain types of packaging and wastes. An example of this is the UK's plan to construct a 'co-located' GDF,

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[7] BEP0 = British Experimental Pile 0, ZEPHYR = experimental fast breeder reactor.

where high (HLW) and intermediate level wastes (ILW) will be disposed of in a single GDF, albeit in different cells within the facility. Of concern in this case are the movement of groundwater, and the durability of the HLW glass in the face of "hyper-alkaline" water from the cementitious ILW cell (Corkhill et al., 2013). Matt elaborated:

> There's a little bit of worry […] that the alkaline plume from the ILW cement-based repository migrates down to the HLW repository, and then there's some unfavourable interactions, some impact on accelerating glass corrosion and so on. So there are some technical worries. (Professor of Nuclear Materials, interview)

Coupled with the potential negative effect the encounter of alkaline plume from cementitious waste packages and HLW glass might have for the ability of glass to contain HLW, is the impact the co-located GDF might have on the siting process. Colin, a member of CoRWM noted that the co-located GDF simplifies the implementation process:

> I understand why government says one GDF would be preferable…it's one planning process; it's one of everything. But there are a number of reasons why one might not be practical. [Y]ou may not have enough geology to put all the waste down there. (CoRWM member, interview)

Along the same lines, Matt posited; "finding a contiguous body of rock, which is of the right size, is problematic. So how you construct the facility within the rock is very much riskier in the sense that you got much less flexibility to change this". So, to return to the main point; uncertainty is dynamic. It emerges from complexity. The complexity of the UK's reactor fleet imposes particular challenges for the management of nuclear wastes. The UK's nuclear waste inventory is diverse and broad (section 4.4). Different reactors create different kinds of wastes, even if their spent fuel is reprocessed – and not all spent fuel will be (Chapter 6). The breadth of the waste inventory and the diversity of wastes pose challenges on the engineering of waste packages. The diversity of the waste packages in turn imposes uncertainties on their ability to contain nuclear waste for as long and as efficiently as required. Meanwhile, a co-located GDF, which aims to ease and simplify the implementation process, might end up complicating the process. The demands on geology, in terms of volume and homogeneity, become more stringent. Complexity, aside from increasing uncertainty, decreases flexibility. More geology is needed for a broader range of wastes and the availability of 'suitable' sites becomes narrowed.

Finland: small scale operations

A year after Finland's first nuclear reactor, Loviisa 1, was connected to the grid, a magazine ran by the Finnish Nuclear Society (*Atomiteknillinen Seura, ATS*) weighed that in terms of nuclear power generation "a small country like Finland is in many ways dependent on leading industrialised nations and the services they provide, such as fuel fabrication and reprocessing of spent nuclear fuel" (ATS, 1978: 17). ATS is a scientific association that covers the nuclear field. Its central task is to provide opportunities for information exchange for professionals employed in the field of nuclear technology.

Indeed, the Finnish nuclear infrastructure pales in comparison to its UK equivalent. While Finland harboured hopes of reprocessing (Chapter 6), it never envisioned the construction of such technology itself and in the end never reprocessed any of its spent fuel. The Finnish nuclear infrastructure is composed of four commercial reactors: two Soviet VVER-40 designs[8] at Loviisa and two BWRs[9] at Olkiluoto, delivered by the Swedish ASEA Atom. The choice of reactor designs was informed by Cold War considerations (Nikula et al., 2012), but, unlike in the UK, reactor choices were not motivated by matters of prestige, but a deliberate attempt to balance between the East and the West.

Both reactor sites also host shallow geological repositories for LLW and ILW. These have been operational since 1998 and 1992, respectively. A US designed TRIGA research reactor that was operated by VTT Technical Research Centre of Finland (VTT) in Espoo has been shutdown and is waiting for decommissioning. Like the UK, Finland fosters ambitions of expand its

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[8] VVER40 = Water-Water Energetic Reactor.

[9] BWR = Boiling Water Reactor.

nuclear capacity. The delivery of the now infamous Olkiluoto 3 EPR is almost a decade late. Initially, commercial operations were meant to start in 2010, but have been pushed back several times. The anticipated start of energy generation has been stated as December 2018. Fennovoima, a relative newcomer in the Finnish nuclear energy scene, is planning to construct another VVER-type reactor in Pyhäjoki, Northern Finland. Like Olkiluoto 3, this project is also behind schedule. The safety documentation produced by Rosatom, the deliverer of the reactor, for the Construction Licence Application (CLA) has not been sufficiently detailed to allow the regulatory body, the Finnish Radiation and Nuclear Safety Authority, (STUK), to assess the safety of the planned reactor (YLE, 2016).

Figure 9. Nuclear places in Finland.

In what follows, I will explore the waste inventories that have been produced at the nuclear sites that I have discussed in this section. In section 4.3 I will discuss current practices of reporting nuclear waste volumes and quantities – and how this might hinder the researcher for fully grasping comparative scales of the nuclear waste challenge.

4.2 Nuclear traces

Nuclear waste inventories are reflections of particular nuclear pasts, past presents, past and present nuclear futures. In the same way as national imaginations are embodied and performed in reactor designs (Hecht, 2009), we can trace echoes of national technopolitical priorities in nuclear waste inventories. The size and complexity of nuclear waste inventories readily reflect past and present visions of nuclear futures. They also differentiate between national experiences of nuclear waste management and plans for GDF designs.

As the stuff for disposal, nuclear wastes are broadly defined as “radioactive material in gaseous, liquid or solid form for which no further use is foreseen” (ENSREG, n.a.). This definition leaves a great deal of space for policy makers to define what materials are considered as wastes and which are not. National nuclear waste inventories, thus, differ in scale and material diversity. These differences can be useful indication of scale of the nuclear waste challenge countries need to address. Simultaneously, differences between waste inventories, as well as nuclear infrastructures, can discourage comparison between different countries. The scales of the UK and Finnish nuclear waste inventories, for instance, are so vastly different, as we will see, that direct comparison between them would provide us with little fruitful material with which to work. However, if we treat waste inventories as effects of past and present decisions, waste management presents, and visions of nuclear futures, they supply material for bringing different disposal projects into a meaningful conversation with each other.

Internationally waste classification practices vary based on national policies and stances on the ontological status of spent nuclear fuel in particular. The World Nuclear Association (WNA) for instance defines spent fuel strictly as an asset, and its three tier classification system includes low level wastes (LLW), intermediate level wastes (ILW) and high level wastes (HLW) (WNA, 2018). Countries that do not reprocess spent fuel include or replace HLW with spent fuel in their classification systems. Table 1 lists the relative volumes and radioactivity levels of the three nuclear waste categories to which the WNA subscribes. Waste categories primarily rely on levels of radioactivity (WNA, 2018), yet both Finland and UK use different approaches to categorise their wastes. On the international level the classification of wastes follows multiple logics, which convolutes the scale of the issue in ways that makes the comparison of different cases difficult. Following Geoff Bowker and Susan Star Leigh (1999) waste classification on the international level is better viewed as a ‘nomenclature’ since there is no single, uniform, classificatory principle to categorise the stuff. A nomenclature is merely an agreed-upon naming scheme that needs not follow particular classificatory principles. Classification practices are blurry, spatio-temporal interventions in the world (Bowker and Leigh Star, 1999). In an ideal case classification practices are consistent and complete, covering the world they seek to describe in its wholeness; while classes, ideally, are mutually exclusive. No real world classification system, Bowker and Leigh Star note, meet these criteria. This becomes even clearer when we try to compare two cases classifying the same or similar matter. Nuclear waste provides us with a prime example of this, and in section 4.3 we will see some of the challenges the varied practices impose on efforts to compare the scale and composition of nuclear waste inventories.

Table 1. Relative Nuclear Waste Volumes and Levels of Radioactivity

	Volume	Radioactivity Level
HLW	3%	95%
ILW	7%	4%
LLW	90%	1%

Adapted from World Nuclear Association (WNA, 2018)

In Finland nuclear wastes are classified according to their disposal route (OECD, 2016). From a practical nuclear waste management perspective this effectively means that there are only two nuclear wastes classes: the GDF bound SNF and operational wastes that includes both LLW and ILW. The vast majority of operational wastes have already been disposed in shallow underground facilities at Olkiluoto and Loviisa as a "routine practice" (VTT Principal Researcher, interview). LLW consists of what could be considered as 'conventional maintenance waste' (Fortum, 2016), that is, machine parts, pipes, work clothing, used protective gear, plastic wrappings, rugs and fabrics. ILW for its part, includes ion exchange resins from water purification systems, evaporation wastes from drainage water purification, sludges that sediments at the bottom of tanks and pumps. Both ILW and LLW are packed into concrete containers and emplaced into silos that have been excavated into the bedrock at the depth of 60-100 metres (TVO, n.a.).

The UK's classification system is more intricate than the Finnish binary system that merely differentiates between SNF and operational wastes. Nuclear wastes are classified according to their heat-generating capacity and activity content into LLW, ILW and HLW (NDA, 2014a). LLW has been disposed of in the LLWR in West Cumbria since the late 1950s, first in disposal trenches and later in engineered vaults. Under the current policy framework all ILW and HLW, and some SNF, will be disposed of in a GDF. SNF has traditionally been treated as a *resource* rather than waste and has been reprocessed. However, under the current policy framework reprocessing is expected to cease by 2020 (DECC, 2015). This transition from an open to a closed fuel cycle means that all SNF from potential nuclear new build will be disposed of alongside ILW and HLW.

Looking at the national nuclear inventories together-apart, names and labels assigned to things are broadly speaking the same: LLW, ILW, HLW, SNF. What these labels describe is less clear. What ILW or SNF are, what they are composed of is hidden and blurred behind the label. Waste classifications name things, but they do not really tell us what things are assembled behind the label, what they are. Their usefulness emerges from the production of relationality within the top-level category of nuclear waste. Although we do not know exactly everything that LLW contains, we know it is different from ILW that is different from HLW that is different from SNF. The significance of these labels emerges through their relationship with each other and the implied effects and threats they can pose to organic life. The indeterminacy of the UK's inventory is not produced solely by policy decisions about reprocessing and indecisions about wastes (chapter 6), but also by improvements in nuclear waste management and compaction techniques, anticipated returns of reprocessing wastes to overseas customers, and uncertainties related to some of the historical wastes stored at Sellafield.

Disposal inventories

While I have here labelled Finland's stock of SNF as a 'waste inventory' for the sake of clarity, the concept of a nuclear waste inventory is absent from Finnish nuclear waste imaginations and terminology. The absence of an explicit inventory can be a hindrance for the researcher trying to make sense of the nuclear waste situation in Finland, a matter I will briefly address further below. Nonetheless, I am bent to propose that the absence of an inventory suggests a measure of clarity and certainty within the Finnish GD project.

The stock for disposal in Finland is reasonably simple. Past waste management practices and regulatory requirements have ensured that the stock is certain, and stable. Since Finland has not shifted between open and closed cycles, there is little uncertainty as to what the matter going into GDF will be. Moreover, the Finnish inventory is small. It is small in contrast to many other nuclear countries, but it is also smaller than it could have been. Between 1981 and 1996 SNF from the Loviisa plant was repatriated first to the Soviet Union and then to Russia. The return was part of an agreement signed between the Soviet and Finnish governments in 1969 regarding peaceful uses of nuclear power. The agreement was in line with the Soviet practice of delivering fuel to and receiving SNF from the reactors it had delivered to other countries (Kojo, 2009). Because of the clarity over what will be disposed of in Onkalo, the Finnish nuclear industry might see no apparent need for an established nuclear waste inventory. Both utility companies, TVO and Fortum, store their SNF at the reactor sites, while operational wastes are disposed of routinely also at the reactor sites. When Posiva applied for the construction licence for Onkalo at Olkiluoto in the late 1990s, the existing amounts and anticipated future risings of spent fuel for disposal had already been calculated and established. There is little uncertainty as to what is going on, what and how much stuff is going into the GDF.

The present situation in the UK stands in contrast to that in Finland. In contrast to Finland, the UK has a 'centralised' nuclear waste inventory that is updated every three years. The latest iteration is from 2016. The inventory has a designated website (https://ukinventory.nda.gov.uk) under the government domain that offers a 'snapshot' of nuclear wastes that have accumulated during present and historical nuclear operations. The website offers also estimates of future arisings from existing reactors. The website further guides the reader on how nuclear wastes and wastestreams are reported, how nuclear wastes are classified, what radioactivity is, how the inventory can be used, and how it should be interpreted.

Additionally, the inventory also provides a list of materials *excluded* from the inventory, and a rationale for these exclusions (NDA, 2014b). Labelled as radioactive materials (in contrast to nuclear wastes), these excluded materials include, but are not confined to, depleted uranium, plutonium and (for now) SNF. This but underlines the ontological indeterminacy, what is waste and what is an asset, of nuclear materials. Take depleted uranium, for instance. It can be used in a range of products. It has been used as a counterbalance weight and ballast in aeroplanes, such as Boeing-747 and boat keels (WHO, 2001). It is however, most commonly associated with military applications. Arthur, an RWM Research Manager criticised the current classification of depleted uranium as a radioactive material. He weighed that once "you recognise that the best thing to do with this depleted uranium is to put it underground rather than to make it into depleted uranium weapons and fire it at people, disposal just seems like such common sense" (RWM Research Manager, interview). Indeed, despite the radioactive material status of depleted uranium, the current government policy requires RWM to consider the disposal of this materials, as well as plutonium. While this arrangement allows some room for manoeuvre for the government with regards to the future treatment of depleted uranium and plutonium, the RWM Research Manager questioned whether this open-endedness and indeterminacy with regards to depleted uranium is necessary, because the material has such limited uses. The situation with plutonium is not dissimilar to that of depleted uranium. The UK government appears to be holding onto its atomic optimism that plutonium will deliver on its historical promise as a valuable energy source. Theoretically, the UK's plutonium stock could be utilised as a component of Mixed Oxide fuel (MOX), a fuel cocktail of uranium and plutonium. Gordon Mackerron (2012) has argued, however, that the costs transforming plutonium into fuel and managing MOX SNF as a result is more costly than the management of 'conventional' SNF. Moreover, MOX is not used in UK reactors currently nor will any of the planned new nuclear plants envision use this fuel.

Aside from depleted uranium and plutonium, the third major source of uncertainty is potential spent fuel from new build reactors – also excluded from the UK's nuclear waste inventory. With new build reactors still sitting on the drawing board, their nuclear wastes have not been "confirmed" and have thus been excluded from the inventory (DECC, 2015). This adds further uncertainty as to the eventual UK nuclear waste inventory. Nonetheless, the government holds that new build SNF could be disposed of in the future GDF (BERR, 2008). Colin, a member of CoRWM, observed that brining SNF into the GD project might prove counterproductive:

> The conflation of new build and legacy wastes is quite uniquely British, but might also prove unhelpful. It would be a much easier task to get people to volunteer for legacy only. (CoRWM member, interview)

'Legacy' wastes, mentioned by Colin, are nuclear wastes that have arisen or will arise from the UK's existing nuclear capacity; so effectively from the weapons programme, the various experimental reactor programmes, nuclear power plants and reprocessing activities. Mackerron notes how "the notion of 'legacy' is […] often invoked to capture the idea that there is a long history of the generation of nuclear materials […] and that there is no choice about the need to find suitable management solutions" (Mackerron, 2012: 7). In ontological terms, legacy is definite. It cannot be undone; it cannot but be waste. This is partly due to the irreversible waste treatment and management practices that will be explored further below in Chapter 6. In its 2002 White Paper, *Managing the Nuclear Legacy*, the UK Department of Transportation (DTI) defined the UK's nuclear legacy as those sites and facilities "developed in the 1940s, 50s and 60s to support the Government's research programmes, and the wastes, materials and spent fuel produced by those programmes; and the Magnox fleet of nuclear power stations designed and built in the 1960s and 70s" (DTI, 2002: 8). This begs the question about the visibility and status of wastes produced and to be produced by the still operating AGRs and the PWR. Where do these fit, categorically? Why are they not seen as part of the nuclear past (the PWR at Sizewell as the youngest reactor is 22 years old) or the nuclear future? These questions might be moot, as wastes from the AGR and PWR are nonetheless being managed and are destined for disposal. The clarity of the boundary work demarcating the past from the present and the future nonetheless is intriguing. It is characteristic of the UK disposal culture, and I will propose in Chapter 7, essential for the performance of *contain-ability*. Before, we return to the stuff of this section, it is also worth noting that UK's practice of delineating nuclear pasts, presents and futures appears in opposition to Finnish imaginations around time and nuclear. Rather than boundaries and ruptures, the Finnish disposal culture emphasises continuity.

Returning to legacy waste, its ontological certainty and the ethical obligation it embodies were at the heart of CoRWM's recommendation of GD as the best available option for the long-term management of nuclear wastes (CoRWM, 2006). The Committee made it clear that its deliberations only dealt with legacy wastes, and it took a clear stance against the conflation of new build and legacy wastes. New build wastes, CoRWM argued, are accompanied by different ethical, political, social and technical considerations. Moreover, the Committee held that at the time when communities are invited to participate in the implementation process

> the inventory of material destined for disposal must be *clearly defined*. Any substantive increase to this inventory would require an additional step in the negotiation process with host communities to allow them to take a decision to accept or reject any additional waste. (CoRWM, 2006: 113, my emphasis)

It can be argued that this, at the moment, is not case. The inventory remains in a state of flux with a range of ‘radioactive materials’, including plutonium and depleted uranium, existing in an ontological limbo. In its 2014 White Paper Implementing Geological Disposal, the now defunct, Department of Energy and Climate Change (DECC) laid out a so called ‘inventory for disposal’ that included everything that *might* be disposed of in a future GDF, including depleted uranium, plutonium and new build SNF. DECC explained that

> it is not anticipated that […] the categories of waste and material […] will change significantly. They provide the most complete picture of the *possible* inventory for disposal, and are presented as such in order to give […] the full picture of the wastes and materials that need to be considered. (DECC 2014a: 14, my emphasis)

While, admittedly DECC’s inventory of disposal lists anything and everything that could go into the GDF and thus in a sense checks CoRWM’s condition on informing substantive nuclear waste increases, it is reasonable to question how clear or informative the inventory for disposal really is. By listing both nuclear wastes and radioactive materials, if we follow the ‘official’ classification, DECC’s inventory for GD does not provide clarity for the UK GD project, but sits awkwardly alongside the UK’s nuclear waste inventory. The messiness of the nuclear waste inventory(/ies), the government’s unwillingness to define the official inventory clearly and assertion that “waste and spent fuel from new nuclear build would not raise such different technical issues compared with nuclear waste from legacy programmes as to require a different technical solution” (BERR, 2008: 90), might well prove detrimental to the implementation of GD. The government’s apparent indecision about or lack of commitment to nuclear waste categories adds unnecessary uncertainty to what the nuclear waste inventory for disposal might eventually be. This indeterminacy about what counts as waste has a negative affect on the GDF’s ability to contain waste. The major question with regards contain-ability emerging from this indeterminacy is; how can you design to contain matter, when you don’t know what it is you are containing? The ability of the GDF to contain nuclear wastes is tied to scientists’ ability to tailor materials of containment to suit the needs of wastes. If there is uncertainty about the wastes, there is bound to be uncertainty about the materials used for their containment. How can you care for something, when you are unsure what it is that you need to care for?

4.3 Reporting wastes

Finally, it is worth pointing out, albeit very briefly, the different waste inventory reporting practices. Making sense of nuclear waste inventories, particularly for comparative purposes can be tedious and frustrating. The ways in which waste are reported draw partly on the classification practices discussed in section 4.1. Comparing waste quantities between and, even within, inventories is a complex undertaking. Table 2 lists the best available information for Finnish and UK nuclear waste inventories. In doing so, it also demonstrates some of the issues with nuclear waste reporting. The quantities of LLW, ILW and HLW are customarily reported in volume (m^3), while in the UK spent fuel is reported by mass (tonnes of heavy metal, tHM). In Finland authorities from Posiva to MEE (Ministry of Employment and Economic Affairs) use tU (tonnes of uranium) instead of tHM for reporting SNF. Additionally, MEE and the regulator STUK report SNF quantities also in numbers of disposable SNF assemblies (MEE, 2017; STUK, 2014). Posiva on the other hand translates this figure into the expected number of waste canisters needed to contain existing and forecasted

Table 2. Indicative nuclear waste Inventories

	UK	FIN
HLW	1,150 m^3	-
ILW	290,000 m^3	9,978 m^3
LLW	1,350,000 m^3	
SNF	7,000 tHM	5,500 tU

Based on data from the UK’s 2016 nuclear waste inventory (NDA, 2017a; NDA, 2018) and data from Posiva’s website (Posiva, n.a.a) and from a 2016 OECD country report on Finland. Thus the FIN data presents the assumed overall SNF arising from the operations of the existing four reactors as well as OL3 still under construction. The figure for ILW and LLW presents the arising by 2015. All the data for the UK presents assumed arisings from closed and currently operating reactors.

SNF arisings from the three reactors at Olkiluoto and the two at Loviisa (Posiva, n.a.a). Numbers of fuel assemblies and waste canisters may be more illustrative and communicable than nuclear waste volumes or masses. Still, as a means relaying the scale of the matter they are extremely vague units, unless the reader is familiar with the dimensions of these objects.

The UK's favoured references to the Wembley stadium, when talking about the quantities of nuclear waste; "the UK has generated a legacy of nuclear waste with a volume capable of filling Wembley Stadium" (University of Sheffield, 2016, see also DECC, 2014a), is as obscure as Finnish references to waste canisters. References to Wembley or to the 2,800 waste canisters anticipated by Posiva, hardly invokes the imaginary that "the amount of nuclear wastes produced is very small" (WNA, 2017b) that nuclear institutions, such as the World Nuclear Association (WNA), seek to promote. Where the nuclear industry draws on Wembley as something relatable, seeking to invoke an imaginable scale for the nuclear issue, Wembley advertises itself as the "largest and most prestigious sports stadium" in the UK (Wembley, 2018). The imaginations of manageability the nuclear industry seeks to invoke are in direct opposition with popular views of Wembley as a large venue. While the Wembley analogue might resonate with broader readership than cubic metres in communicating the scale of the issue, it might nonetheless guides imaginations in unwanted ways. Moreover, one might also argue, that situating nuclear waste in such a mundane setting decentres wastes from the representation of the scale of the problem by drawing attention to the actual venue or memories of Alan Shearer scoring five goals in Wembley in the 1996 UEFA Euros.

If practices of reporting nuclear waste quantities are diverse and unnecessarily cumbersome to interpret, the actual terminology and labelling of nuclear wastes work the other way around. Both in the UK and Finland the terminology used to describe nuclear wastes tends to do away with much of the messiness contained by the terms. When referred to in the singular: "UK Radioactive Waste Inventory" (NDA, 2018b), "how the waste and materials are currently managed" (DECC, 2014a: 15), "no nuclear waste will be released to living nature" (Posiva, n.a.b), much of the diversity within and between nuclear waste classes becomes invisibilised. All the while though, the diversity within different classes provides Waste management organisations with engineering and nuclear waste management conundrums. Even in the Finnish case where only spent fuel is a concern for the GD project, the broad category of spent fuel includes three different kinds of spent fuels each of which requires a unique waste canister as the fuel assemblies for the BWR, EPR and VVER-440 are of different sizes. The UK's ILW, for instance, emerges in many forms: fuel cladding material, sludges, ion exchange resins, plutonium contaminated materials and solids from plant operation and maintenance. Based on the activity levels of these wastes and the related requirement for their packaging and shielding, ILW is internally divided into two categories: ILW and UILW (unshielded ILW), the latter category being the one needing more treatment due to its higher levels of activity. DECC has described this division as "important for the safety of operation and the design of both stores and disposal facilities" (DECC, 2015: 36). Similar considerations are relevant for all of the different types of nuclear wastes, as none of the categories is internally homogeneous.

While short-hands and the simplification of nuclear wastes might ease communication, they do obscure the very tangible relationship between nuclear wastes, wasteforms and GDF design. How and what material is classified affects how and what disposal cultures do and act in the world. A three or four tier classification of nuclear wastes, as an ideal classification practice skims over what it classifies. It ignores the liveliness, evolution and changeability of stuff, as well as the ability of humans to change their minds about what counts as what and why. The more diverse the inventory of nuclear wastes, the more there are different kinds of wasteforms and materials present in the GDF design, the more challenging the implementation of GD is likely to be. Classification invests the classifier with agency. It implies controllability, whereas the 'need' to classify nuclear things, emerges from a lack of control.

We can undestand nuclear waste classification practices as mechanisms of care and protection of the human. It is exactly because of their liveliness and invisible power to corrupt that nuclear waste needs to be classified, not for the sake of wastes but for the sake of the human. Unable to see, feel or detect their liveliness sensorially or in other ways, we need waste classes and labels for our own protection. We are immersed in and motivated by the logic and stickiness of nuclear radiation and waste as hyperobjects. Their effects are inescapable in their human-scale 'foreverness'. Thus a way of claiming agency over the unruly matter, disposal cultures split it, box it, contain it discursively in neat categories that in the end of the day only bear relevance to other categories. The waste itself could not care less about the name we give it. Waste will continue to do what it does whether we admit its ability to do so or not.

In the following two sections I will explore some of the spaces and practices through which nuclear wastes and inventories have been imagined and engineered, and how this has fed to imaginations of a 'nuclear waste problem'.

4.4 From manageability to a threat

In the early years of the nuclear age the stuff churned out by nuclear power stations in the UK had an ambiguous status. It flowed freely between imaginations of waste and asset, but the underlining notion was that the stuff was manageable. In a 1958 House of Commons debate, Winston Churchill asserted, "the radioactivity of waste released from the civil nuclear power stations is expected to be negligible" (HoC, 1958, vol. 583, c. 969). While for Chruchill radiation was a non-issue, concerns about nuclear waste had been voiced earlier. During a 1954 House of Lords debate the Marquess of Salisbury posited waste explicitly as a problem:

> The widespread use of atomic energy is bringing with it a new problem [...] a new industrial waste which is *highly dangerous* and contains radioactivity greater by several orders of magnitude than anything that has been known before. (HoL, 1954, vol.187, c. 478, my emphasis)

Although Salisbury viewed nuclear waste as a 'highly dangerous' problem, he observed that the industry had paid special attention to the waste problem, and further perceived radiation as controllable:

> The atomic energy project has always devoted special attention to this new problem. *The greatest care* has been taken not to allow discharges which could give rise to any contamination of air or water

> exceeding the levels laid down by the Medical Research Council. (ibid., my emphasis)

According to Salisbury, then, careful industrial and regulatory practices were adequate to contain and keep the new problem of radiation under control. This narrative of controllability was reiterated in the 1955 White Paper *A Programme of Nuclear Power* that laid the foundation for the UK's first civilian nuclear programme. In the first instance, the Paper posited that the volumes of waste generated by the nuclear industry would be small, while efforts to identify storage and disposal solutions had already commenced. Moreover, the Paper asserted

> The disposal of radioactive waste products should not present a major difficulty. *The problem is primarily one for the chemical processing plants*, which will be few in number, and not for the power stations. (Ministry of Fuel and Power, 1955: 9, my emphasis).

The perceived small volume of waste together with the presence of reprocessing technologies helped to invisibilise and deproblematise waste matters. Rather than waste, spent nuclear fuel was conceptualised as an asset to be reprocessed and reused. Any waste produced was defined in terms of its chemistry rather than its nuclearity (Hecht, 2009). The White Paper further envisioned "many valuable uses for [radioactive waste products] which may be able to absorb a great part of the output" (ibid: 9). A few years later, Lord Mills went as far as to argue; "there is no waste from a nuclear power station. [R]adioactive material will be re-processed and most valuable products will be obtained from [it]" (HoL, 1957, vol. 202, cc. 1014-1015). Since the early motivation behind civilian nuclear power was the generation of raw materials for nuclear weapons, the positing of spent nuclear fuel as an asset rather than waste is unsurprising. In a debate on the 1955 White Paper, MP Nigel Birch made this point explicit. He held that the UK was developing techniques for 'waste' by-products such as Strontium-90 and Caesium-137 to "put them to useful work" (HoC, 1955, vol. 537, c. 1675). Strontium-90, he explained, could be used to prevent static electrical build-up in industrial processes, while Caesium-137 could have medical uses. "The point", Birch emphasised, was that waste “is a *manageable problem*” (ibid, my emphasis). Not only was spent fuel considered manageable, waste disposal itself was seen as unproblematic. Wishing to address public “misunderstanding” of the risks of disposal, MP Ronald Bell observed in the same House of Commons debate that “the disposal of even the great and increasing volume of atomic waste […] will cause no serious trouble at all in the years that lie ahead. [T]he disposal of the processed waste can be easily undertaken without any danger to the surrounding population” (HoC, 1955, vol. 537, c. 1634). Wastes and disposal were, thus, construed as non-issues.

The presence of reprocessing technologies enabled the separation of nuclear technology and spent fuel. Rather than waste, spent fuel was primarily viewed as an asset, while high level waste was defined through its chemistry rather than its nuclearity. Together, these two factors contributed to the narrative of controllability of waste. Even where waste was problematised, the underlining story was one of manageability. This narrative of the manageability and controllability of nuclear waste has not change significantly although wastes have since been problematised.

The Flowers Report

Where the 1955 White Paper posited nuclear spent fuel as a manageable asset on one hand, and as chemical waste on the other, the 1976 ‘Flowers Report ‘presents us with a marked break in the narrative of the controllability of nuclear materials. The Report was published as a response to the UK Government’s plans to implement a new nuclear programme envisioning a “twenty-fold increase by year 2000 and a further quadrupling by year 2030” of the country’s nuclear capacity (RCEP, 1976: 3). Facing this vision of the UK’s nuclear future, the Royal Commission on Environmental Pollution (RCEP), lead by sir Brian Flowers, felt that the environmental implications of such a nuclear expansion should be examined in depth. As the first serious consideration of the waste issue (among other nuclear matters), the Flowers Report has been referred to as the ending of the UK’s nuclear waste management “pre-history” (Cairns, 2014), and RWM, as the current developer of the UK GDF, traces its origins to the Report (Wisbey, 2017). In a marked departure from the nuclear waste debates of the 1950s, the Flowers Report describes wastes in terms of their nuclearity and futurity.

> “There is the *problem* of dealing with the highly active radioactive *wastes which arise in the nuclear fuel cycle* and which will have to be contained for *immense periods of time*” (ibid.: 3, my emphasis).

Rather than chemistry, the Report defines the waste and the waste problem through their nuclearity. This shift from chemistry to nuclearity challenged the narrative of controllability. Waste matter was no longer something that could be managed in the present, but that had to be managed into the distant future. The Report explicitly criticised the UK’s nuclear establishment for neglecting nuclear waste.

> The picture that emerges from our review of radioactive waste management is in many ways a disquieting one, indicating insufficient appreciation of long-term requirements either by government departments or by other organisations concerned. (RCEP, 1976: 162).

The UK nuclear establishment, the Report observed did not give “any indication that they regarded the search for a means of final disposal of highly active waste as at all pressing” (RCEP, 1976: 149). It found “this the more surprising in view of the large nuclear programmes […] envisage[d] for the coming decades, which would give rise to much greater quantities of waste” (ibid.). The stance of the UK Department of Energy that “safety and environmental problems related to nuclear power could be overcome”, was criticised by the Report that argued that such a stance “could lead to recognition of the dangers when it would be too late to avoid them. More is needed than bland, unsubstantiated official assurance that the environmental impact of nuclear power has been fully taken into account” (RCEP, 1976: 198). The Report effectively accused the UK nuclear establishment for structural irresponsibility, the “pursuit of progress […] creat[ing] ever greater timeprints marked by fundamental uncertainty and indeterminacy” (Adam and Groves, 2007: 203). The UK nuclear establishment, the Report contended, was appropriating the future in service of the present through its negligence of the latent consequences of nuclear operations, which were already emerging as problematic to manage in the very long-term. The Report concluded that it would be “irresponsible and morally wrong” to commit future generations to nuclear new build if it could not be “demonstrated beyond reasonable doubt that at least one method exists for the safe isolation [of wastes] for the indefinite future” (RCEP, 1976: 80-1). The demonstration of a safe disposal method, the Report posited, should “be an *essential prerequisite* to a big expansion of nuclear power” (ibid.: 152). Rather than something that could be kept under review, the Flowers Report posited nuclear waste as a matter requiring action. The narrative of manageability shifted towards the need to actively manage nuclear waste.

Underlining the responsibility of the present for the future, the Report criticised not only the government’s eagerness to commit to nuclear power, but also the industry’s nuclear waste management practices. It picked on the “standards of general housekeeping” at the BNFL-controlled Sellafield site, which the Report considered were not on a sufficiently high level (ibid.: 151). While the storage of waste in tanks and accessible facilities at Sellafield was posited as “safe enough for the present”, these practices, the Report deemed, were “unacceptable as a long term solution” (ibid.: 80). The Report expressed further disapproval of the decade-long stagnation in the research and development of vitrification, which can be seen as contributing towards a long-term waste management solution. Vitrification today is a standard technique for converting liquid HLW into a solid and stable glass form. Research into vitrifcation begun in the UK in the 1950s, but it had been virtually halted in the 1960s. While this research had since recommenced and the vitrification of HLW was expected to begin in the mid-1980s, the Report noted that that it was “strange in retrospect that a matter so important for the safe development of nuclear power should have been delayed for so long […] since vitfirication is intended not only to facilitate ultimate disposal of the wastes, but also to make them more secure […] in the interim” period before disposal (ibid.: 145-6). As the UK nuclear establishment was driven by the promises of nuclear technology, military and energy security considerations, whatever early concerns there were about waste were muted by a narrative of controllability, and it was not until the Flowers Report that nuclear waste was construed as a ‘matter of care’ (Puig de la Bellacasa, 2017), and a serious problem.

In a significant break with past nuclear future making, the Flowers Report situated the management of nuclear wastes ahead of the development and expansion of nuclear power technology. Nuclear waste, the Report held, should be addressed before any nuclear new build plans were realised. The Report highlighted the intergenerational cost of “cheap power” (Ministry of Fuel and Supply, 1955: 8) arguing that nuclear power imposes “dangers to our remote descendants long after nuclear fission technology has ceased to be used as a source of energy” (ibid.: 192). While the Report did not advocate the curbing of existing nuclear energy generation, it nonetheless argued that the hazards of nuclear wastes were significant enough to argue against a careless commitment to nuclear expansion “in the hope that [such expansion] might be avoided altogether” (ibid.: 195). Nuclear waste, the Report argued, is not just “another problem arising from nuclear development […] which can certainly be solved given suitable control arrangements” (ibid.: 193). While nuclear wastes are controllable in the present, their production has set in motion futures with repercussions that escape the reach of contemporary industrial and regulatory arrangements to manage them in the long-term. Without adequate long-term waste management solutions, the Flowers Report argued, there is no moral basis to expand nuclear for the benefit and purposes of the present at the expense of the future.

This positioning of long-term waste management solutions as a prerequisite for nuclear expansion was echoed by the UK Department of Energy and Climate Change (DECC) three decades later. In a 2014 press release DECC asserted; “building a GDF will help us permanently deal with waste [...] It will also support the development of new, low-carbon, nuclear electricity generation in the UK by ensuring there is a safe, modern facility for permanently disposing of waste” (DECC, 2014a). In this framing, the GDF has been solidified as the signifier of the responsibility of the present for the future. It is broadly accepted that the generations that have benefitted from nuclear power should take care of nuclear waste to “lessen the burden on future generations” (Wilkinson, 2007: 220, see also CoRWM, 2006). Concurrently, the OECD notes, the international nuclear waste community perceives GD as “an ethical undertaking that should be pursued now, and not left to future generations” (OECD, 2000: 15). While, it can thus be argued that GD is seen by the nuclear waste community as a “material vital doing, and an ethico-political obligation” (Puig de la Bellacasa, 2011), the extent of its ethical justification for nuclear development and new build has been contested in the UK. On the other hand, as we will explore in section 4.6, it can be argued that emphasis on nuclear development has stood in the way of caring for the waste problem. As we will see in Chapter 6, CoRWM (2006) has argued that different ethical criteria applies to the management of ‘historical’ and potential new build wastes. The acknowledgement and acceptance of responsibility, and the provision of a potential long-term solution to management of nuclear waste, CoRWM argues, is not a licence to exacerbate the waste problem and to subject future beings to potential hazard.

4.5 From a problem to a solution

Where the UK began with a benign view of nuclear wastes as an asset and a manageable problem, the Finns approached the waste management issue from a different angle. Three years after the first reactor was connected to the grid, MP Mauri Pekkarinen argued in a 1980 parliamentary debate; “the fate of nuclear fuel waste in particular is a major problem in the very definition of the word” (PTK37/1980: 937). In contrast to the prevailing UK narrative of controllability and the negligence of waste in practice (section 4.6), from the beginning the Finns were more prone to conceptualise waste as a problem that required a long-term solution. However, the Finnish approach to waste matter in the early years of the nuclear industry, too, was more ambiguous than clear-cut. In 1976 (a year before the first reactor was connected to the grid), the Ministry of Trade and Industry (MTI) established a working group of national nuclear experts from the industry, academia and the civil service to present ideas for organising nuclear waste management and to “review matters and research it consider[ed] urgent” (ATS, 1978: 16) for the implementation of nuclear waste management. In its report the group held that spent fuel constituted the “most problematic question in nuclear waste management” (ibid.: 18). The group argued that immediate action should be taken to amend the existing Finnish Atomic Energy Law to include the until then omitted nuclear waste management in nuclear legislation; to obligate nuclear power companies to carry the costs of nuclear waste management; to establish a nuclear waste research programme coordinated and overseen by the MTI; to foster international research links; and to prepare for a number of nuclear waste management scenarios. The group's proposal translated into a 1978 Decision-in-Principle (DiP), which held that plans for the long-term management of nuclear waste were a prerequisite for nuclear power plant operational licences. In other words, nuclear waste management was tied to present nuclear operations; consideration of the future was situated as a prerequisite for present operations. Ilkka, a retired Posiva Advisor, noted that TVO, that unlike IVO had no long-term management plan in place in the late 1970s, was forced to address the waste problem with urgency in order to secure their operational licence which "would not be renewed if the [waste management] programme wasn't started. [The DiP] was a clear whip and a signal that action needed to be taken immediately". The decision-making circles in Finland, then, were sensitive to nuclear waste as a problem that could not be left to wait for the future. However, it was waste management, rather than waste itself, that was perceived as a challenge. As in the UK, spent nuclear fuel was seen as an asset. In its report, the MTI appointed working group postulated that the "direct disposal of spent fuel as waste is […] an unlikely option, because it would mean wasting resources" (ATS, 1978: 18).

Reprocessing, rather than disposal, was, thus, the early favourite for nuclear waste management in Finland. It was seen as economically the most sensible alternative, but also as the *safer* alternative to the disposal of spent nuclear fuel. The 1978 Nuclear Waste Report established that "reprocessing wastes are seen to be in a safer form than spent fuel. Vitrified high-level waste […] has a low solubility and it contains only a fraction of the amount of plutonium in spent fuel" (IVO and TVO, 1978: 32). Nonetheless, because of the small scale and limited resources of the Finnish nuclear industry, establishing native reprocessing capacity was considered unpracticable. Spent fuel would have to be reprocessed abroad, where it was hoped the high level wastes resulting from reprocessing would also stay after reprocessing. The MTI working group argued, "sending [spent fuel] abroad irreversibly should be the first aim for Finland" (ATS, 1978: 18). In this way, it was imagined that the management of Finnish nuclear wastes could be delegated to other nuclear countries, and TVO embarked on negotiations with BNFL in the UK. The state-owned IVO already had waste management arrangements in place. It had signed a deal with the Soviet Atomenergoexport, who delivered IVO's reactors at Loviisa, in 1969 over the repatriation of spent fuel to the Soviet Union. The negotiations between TVO and BNFL, however, soured fast and eventually broke down, as the two companies fundamentally disagreed over the fate of HLW. Where TVO envisioned reprocessing as virtual disposal of its wastes abroad, BNFL demanded that HLW should be returned to Finland. A parliamentary debate took place against the breakdown of the negotiations between TVO and BNFL. The breakdown raised concerns about TVO's ability to manage its waste in the parliament. Invoking the 1978 DiP, MP Mauri Pekkarinen argued that TVO "should urgently present its plans for solving the waste problem. Unless such a plan can be presented […] their operational licences should be reconsidered" (PTK 37/1980: 938). The failure to reach an agreement with BNFL, at least theoretically, threatened TVO's short-term future. In the absence of satisfactory waste management plans, TVO's initial operational licence covered only five years, up to 1983. The Finnish nuclear regulatory practices brought the long-term future to the present to organise the nuclear industry to prevent major nuclear waste management problems and radiological threats in the future. The nuclear present was governed through the anticipation of future problems. "Anticipatory modes", Adams, Murphy and Clarke argue, "enable the production of possible futures that are lived and felt as inevitable in the present, rendering hope and fear as important" (Adams, Murphy and Clarke, 2009: 248). An anticipated problematic nuclear waste future was invoked to create practices and trajectories that would avoid the envisioned problem. The short-term nuclear future was presented as conditional on the development of nuclear waste management solutions in the long-term.

Where in the late 1970s and early 1980s nuclear waste was a *present problem* for the UK, in Finland the problem, in practical management terms, still lay *in the future*. As a latecomer to the nuclear family, Finland benefitted from international experience of dealing (or not) with nuclear waste. Sweden, in particular, was an important influence (Äikäs, 2016). In Sweden, nuclear waste and its long-term management became politicised during the 1970s, as the anti-nuclear Centre Party wished to phase out nuclear power. Convinced that nuclear wastes presented a problem for the industry, the party hoped to deal a deadly blow to the industry by exposing the waste problem through new legislation. The Nuclear Power Stipulation Act, passed in early 1977 posited that nuclear power companies had to demonstrate both a method and a site for an ‘absolutely safe’ way to dispose of nuclear wastes as a precondition for further construction licences (Elam and Sundqvist, 2010). The Stipulation Act triggered the development of the KBS-3 concept that is currently being implemented in Sweden as well as in Finland. Markku, a Professor of Engineering contemplated “when you have Sweden as a neighbour, that’s where the ideas come from, that we have to do something as well”.

The 1978 DiP, echoing the Swedish Stipulation Act, established the long-term management of nuclear wastes as the “end point of the [nuclear] project that has to be taken care of” (MEE civil servant, interview). Yet in the 1980 debate following the breakdown of negotiations between TVO and the BNFL, MP Terhi Nieminen-Mäkynen argued that “research into nuclear wastes and the problems related to their management have been overlooked. We have, apparently, been naively imagining that […] the wastes will be shipped abroad and that’s that” (PTK 37/1980: 949). More than anything, this accusation is probably suggestive of the intensity with which TVO wanted to dispose of its waste abroad. The MTI working group had already acknowledged in its Report the “possibility that high-activity reprocessing waste will be returned to Finland” and further noted how the “country must take this possibility into consideration and take the appropriate measures in time” (ATS, 1978: 20). TVO’s failed negotiations with the BNFL narrowed down the company’s waste management options to a choice between storage and disposal. In 1982 TVO presented its renewed plan for the long-term management of nuclear waste to the government that proceeded to ratify the plan. While disposal abroad continued to be TVO’s favoured waste management policy (Nikula et al., 2012), the search for a disposal site in Finland began in 1983. The ratification of TVO’s plan together with beginning of the siting process, as we will see in chapter 6, have become important actors in the making of a narrative of Finnish GD success.

The early 1980s imagination of waste management as a problem began to shift as the siting process reached the early 1990s and narrowed its focus from an original 101 potential disposal sites to only four sites. The re-articulation of the problem narrative began with a proposal to amend the 1987 Nuclear Energy Act. The Proposal observed the limited international progress made in the implementation of nuclear waste disposal and argued that “Finland’s […] disposal plans are highly likely to attract international interest as the final disposal problem continues to grow” everywhere (LA 8/1993: 1). Because of the lack of international progress, the Proposal argued, “pressure will be focused on countries, where *the final disposal problem is considered as technically solved*” (ibid., my emphasis). In a decade, the Finnish narrative of the long-term management of nuclear wastes shifted from a problem to ‘technically solved’ despite the lack of a disposal site and the fact that the disposal concept could not be finalised until the site was chosen. The relative advancement of the Finnish project was framed against the perceived stagnation in other countries that was further supported by the problematisation of ‘*foreign’* nuclear waste. In effect, the proposal to amend the Nuclear Energy Act created two new waste categories: ‘ours’ and ‘theirs’, and positioned the latter as a problem. The fear was that the comparatively advanced Finnish project would awaken desires in other countries to ship their waste to Finland for disposal. What had been the original aim of the Finnish nuclear industry, disposal of Finnish waste abroad, came to be seen as the ultimate horror scenario, disposal of foreign waste at home. So, the policy proposal can be understood in terms of efforts to avoid undesirable futures, at this instance, the perceived threat that Finland might be made the disposal site of other countries’ wastes. These concerns were triggered by Finland’s EU membership negotiations, as it was feared that within the EU, under the Euratom Treaty, nuclear materials, including wastes, might travel freely. The concern was that this might result in pressure on countries with more advanced disposal projects to accept waste from struggling projects or countries. By proposing to implement national legislation forbidding the importation and exportation of nuclear wastes, the Proposal sought to avert a fearful nuclear future.

The Nuclear Energy Act was amended in 1994. It posited, “nuclear wastes generated in connection with or as a result of use of nuclear energy elsewhere than in Finland shall not be handled, stored and permanently disposed of in Finland”, while wastes generated in Finland would be disposed of in Finland and only in Finland (YeL, 1420/1994: 4). The Act had three significant repercussions for the Finnish GD project. Firstly, it erased IVO's nuclear waste management strategy, as the company was no longer able to send its spent fuel to Russia. As a consequence the Finnish disposal inventory, that had only contained TVO's spent fuel until then, was expanded and diversified. Secondly, the Act, indirectly, led to the establishment of Posiva. Now that both TVO and IVO were liable to implement GD in Finland, they joined forces and established Posiva as the GD delivery organisation. Thirdly, the Act effectively smothered any residual hopes of reprocessing and disposal abroad. This consequently defined the disposal inventory clearly: only spent fuel would be disposed of in the future GDF. Until the passing of the Act theoretically, if not necessarily in practice, there were four possible routes the Finnish disposal project could have followed. These had been identified by the MTI working group as

- Reprocessing and disposal abroad
- Interim storage of SNF for a sufficiently long period of time
- Storage and disposal of solidified reprocessing waste
- Storage and direct disposal of SNF.

The Act effectively completed the narrowing down of nuclear waste management options, which had begun with the failed negotiation between TVO and BNFL. At this point the future of waste management was framed as an either-or choice between interim storage and direct disposal. Ilkka, a retired Posiva Advisor, recollected how Posiva underlined in public discussions preceding the 2001 siting decisions that long-term waste management in Finland was effectively a choice between two alternatives that should be weighed against each other:

> I was there following the final discussions in the Parliament and it was pleasing to hear that what was being discussed were the available alternatives. […] This is what we had been trying to achieve, so we considered it our success. We were open about uncertainties […] and tried to specifically argue that [GD] in any case is a better alternative than interim storage.

The contrasting of the storage and disposal alternatives, as opposed to more complex scientific debates, in the parliamentary debate can be seen as an expression of the type of engineering pragmatism that has been seen to characterise the Finnish GD project (e.g. van Luik in Manaugh and Twilley, 2012). Ilkka suggested, “even though it may sound a bit naïve, cold pragmatism can be quite important […] for better or worse. It has [led to] bypassing some difficult questions too silently […] but the big thing is […] to think what the available alternatives here are”. This weighing of the two available alternatives against each (disposal against storage) has played a central part in the making of safety, as we will see in chapter 5.

In the next section, I will change pace and engage in speculative thinking about the nuclear waste challenge as a result of ‘our’ infatuation with nuclear things.

4.6 Nuclear love, actually?

Beginning with a broader discussion, but then focusing on the UK’s case, I propose in this section that the nuclear waste challenge has emerged from our love, rather than fear, of nuclear technologies.

If anything, nuclear has always been a technology of the future. Even Disney, in *Our Friend the Atom* (Disney, 1956), engaged with and promoted nuclear as a genie, an omnipotent power to move societies forward. In the prologue, Walt Disney wrote of nuclear as promising a great future.

> The atom is our future. […] The story of the atom is a fascinating tale of human quest for knowledge, a story of scientific adventure and success. Atomic science began as positive, creative thought. It has created modern science with its many benefits for mankind. (Quoted in Sorene, 2015)

Disney’s narrative of scientific success, modernity and progress have been very much part of more official nuclear imaginations as well. Nuclear has always had great promises to offer. While nuclear’s awesome capacity for destruction has suggested the always possible coming of doomsday (Anders, 1962; Weart, 1988), in their peaceful uses nuclear technologies have promised national prestige (e.g. Hecht, 2009; Mackerron, 2012) and electricity too cheap to meter (Macfarlane, 2017). The IAEA, the international body regulating, but also promoting nuclear technologies, envisions nuclear technologies as a means to improve health care, agricultural productivity and food security (IAEA, 1986; IAEA, 2017). Overall, in these imaginations nuclear technology is seen as a vessel for better lives and higher living standards.

Recently, the traditionally concrete anti-nuclear stance of the environmental movement has splintered as more pro-nuclear voices have been heard from prominent members of the movement (e.g. Monbiot, 2011). This shift in stance links back to Disney's narrative of progress and benefits, and adds an ethical commitment to the future. Nuclear power is posited as a climate change mitigator, a zero to low emissions energy technology providing 'clean, green energy' for the future (DECC, 2014b; Bickertaff et al., 2008). These claims remain controversial and have been contested (Adam and Groves, 2007; Caldicott, 2007). Nonetheless, nuclear has been supported by and supports a powerful imagination of technopolitical modernisation (Hecht, 2009, 2012; Jasanoff and Kim, 2009). Modernity, Latour holds, "is the thrusting-forward arrow of time — Progress — characterized by its juvenile enthusiasm, risk taking, frontier spirit, optimism, and indifference to the past" (Latour, 2011a: 21). These, as I will demonstrate, are the qualities and characteristics the UK disposal culture mobilises to justify the UK nuclear establishment's long negligence of nuclear waste.

As a promise of progress and a symbol of modernity, nuclear technology invokes advocacy. To advocate is to care (Code, 2015) and to care is an attempt to intervene (Haraway, 2016), to make a difference in the world. Adam and Groves note how for instance a US based nuclear advocacy group Eagle Alliance envisions a future in which science is fully committed to serve humanity to foster a more equal and sustainable global society. The Alliance believes that "this vision [of an equal and sustainable global society] cannot be realised without nuclear" (quoted in Adam and Groves, 2007: 83). The Alliance, echoing Disney, argues, "nuclear technologies, used in medical diagnostics and treatment, industrial processes, agriculture, food preservation, and energy, have proven beyond question to be a major benefit to all humanity" (ibid.).

Nuclear technology in its multiplicity is presented with the capacity to improve, even save, lives, and in general, to advance societal wellbeing. Through such a narrative of benefits, the Alliance invites readers to care about nuclear, seeking to convince them why nuclear matters; why contemporary societies should (continue to) embrace and push ahead with nuclear technologies. Potential risks are pushed aside as nuclear is imagined as a gift that keeps on giving.

The better future promised by nuclear is, however, mostly contained at reactor sites. The different stages of the nuclear fuel cycle are absent from this heroic nuclear narrative of progress, including stories of climate change mitigation, cheap electricity and improved healthcare. Adam and Groves (2007) have criticised nuclear future making as irresponsible. The promise of nuclear requires that what counts as nuclear industry is confined to operating power plants. They argue that the problem with the narrative of nuclear as a climate change mitigator, for instance, is that what is included in calculations of nuclear's carbon dioxide (CO_2) emissions is unclear. This uncertainty about nuclear's actual emissions renders nuclear's promise of clean energy difficult to verify. To understand nuclear power as the solution to climate change necessitates, according to Adam and Groves, the negligence of the CO_2 emissions that arise from the construction of power plants and from uranium mining, and further how these contribute to global emissions. Adam and Groves point to a study describing how the production of one tonne of cement (the construction of a power plant demands approximately 14 million tonnes of concrete and 1.6 million tonnes of steel) produces one tonne of CO_2, which is dissipated into the atmosphere. The mining of uranium, on the other hand, demands more energy than it produces, while also being a highly polluting activity. Gabrielle Hecht (2012, 2017) furthermore has pointed out that in the uranium mines the futures of miners and their communities are neglected alongside health and safety regulations. Uranium mines, Hecht notes, have been at the margins of the nuclear industry. Next to weapons and reactors, mining is more readily aligned with other forms of mining endeavours than with other nuclear things and activities. As *nuclear* risks in mines have been invisibilised, Hecht argues, occupational hazards are constructed as banal and manageable.

The promise of nuclear and the narrative of progress thus appear to rely on the invisibilisation and externalisation of the human and environmental costs of nuclear technology and narrow definitions of what counts as nuclear activities. The story of nuclear so far reflects how the advocacy and promise of nuclear rely on boundary work, the thinness of definitions and imaginations of nuclear. Therefore it is worth asking what kinds of worlds are being maintained at the cost of others (Puig de la Bellacasa, 2017)? What is the cost of modernity and progress, as envisioned through nuclear? What is the cost of nuclear futures?

UK the nuclear pioneer

The desire for progress and the wish for modernity guide societal concerns, what societies do, what they care about. “Our fetishes”, Hecht posits, “keep us close to bombs and reactors and far from other places where nuclearity gets made and unmade. We have become complacent and complicit in the equation between nuclearity and “development”” (Hecht, 2012: 39). The heroic nuclear narrative has been told and retold through the exclusion of mines, miners, construction work, and waste – the afterthought of the nuclear project. The infatuation with nuclear can only really be justified by the exclusion and invisibilisation of concerns contesting the promise of nuclear.

Three years after the first commercial nuclear reactor was connected to the national grid in the UK, MP Arthur Palmer voiced his concerns, in a 1959 House of Commons debate, that the country was plunging into the nuclear field with too much enthusiasm. This, he posited, could undermine energy security, because, as he saw it, the eager commitment to nuclear might jeopardise the standing of conventional energy sources such as coal. He contested that the promise of immediate cheap energy from nuclear had already been revised and pushed back by Sir Christopher Hinton, the head of Central Energy Generating Board. Moreover, Palmer urged care in the development of the UK’s nuclear industry.

> Other countries are obviously proceeding with caution in this matter. They realise, as we must all realise, that nuclear techniques are changing all the time and that we are only at the beginning of the road. They certainly do not wish to be caught out with a lot of capital

> tied up in the wrong designs. […] They are not rushing ahead over-fast with nuclear development. (HoC, 1959, vol. 608, cc. 574-5)

Palmer did not argue against nuclear *per se*, but held that the UK should take a step back, slow down and review all the available reactor choices. His concern was that the UK's rush to push ahead with a particular reactor design at any cost (Mackerron, 2012) might result in technological and financial commitments that the country might come to regret in the future. In his response to Palmer, the State Secretary of Power Sir Ian Horobin dismissed this proposition to reconsider all available alternatives as disruptive to the UK's nuclear future. Horobin underlined the care with which the UK's nuclear programme had been considered and conceived. He argued that Palmer's proposition represented the kind of short-termism that would be harmful for the development of the civilian nuclear industry and nuclear capacity in the UK.

> If we are right in setting to work to build up an industry capable of developing these new sources of scientific power, it becomes clear that we cannot chop and change on short-term considerations. The British nuclear programme is a very carefully considered whole. No one will say that the industry will not make mistakes in future, although we have been remarkably free from them hitherto owing to the skill of those concerned. […] I think it is very important that everybody should realise that *a nuclear programme on the scale of this country's must be a long-term, carefully-balanced programme and cannot be interrupted by fits and starts and lurches in response to short-term considerations*. (HoC, 1959, vol. 608, cc. 579-82, my emphasis)

Although Horobin highlighted the need for long-term planning in the making of the UK's nuclear industry and nuclear future, it is notable that this 'long-termism' does not extend beyond energy generation. The management of nuclear materials and waste do not feature in his argumentation for long-term planning, neither were they raised as concerns by Palmer in the first instance. Horobin also argued that the nuclear industry should be left alone to implement the planned and debated AGR fleet. Interference, he held, would destabilise the nuclear industry. “We have to take a big view on this”, Horobin argued, “the need for thought and care in investment and design is great […] but I do hope […] Members [of the House of Commons] resist at all costs any injudicious interference with the proper development of that programme” (ibid., c 582). The industry, rather than Whitehall, was positioned as the capable, and responsible, party for the development of the UK’s nuclear future. This effectively meant that the nuclear “programme was pursued without being subjected to justification in economic terms, and without the scrutiny applied to other public spending” (Mackerron, 2012: 9). A vessel for international prestige and leadership, nuclear was seen to have value in and of itself.

Moreover Horobin, by inhabiting the cutting edge of nuclear science and technology, proclaimed, the UK was not “just a major nuclear Power”, but “the major nuclear Power” (HoC, 1959, vol. 608, c 582). To retain its position as the major power, the UK, he insisted, should push ahead with the AGR programme. The single-minded focus on progress and development of the nuclear industry allowed Horobin to invoke the sort of enthusiastic and risk-taking frontier spirit characteristic of future making described by Latour (2011a) and Adam and Groves (2007). The desire to occupy the cutting edge of nuclear technology lead the UK industry to a path of haphazard rector development without commitment to a particular design, as we saw earlier in this chapter, more than five decades later, a former member of CoRWM reflected that the UK nuclear industry was swept away by its initial commercial success. While this approach and a narrow focus on reactor development contributed to the subsequent nuclear waste management challenge, nuclear technology still continues to be envisioned as a source of opportunity rather than as a technology the use of which should potentially be re-evaluated, because of its long-term effects.

The early years of the UK nuclear industry have become romanticised by the UK’s nuclear establishment, while the pioneering spirit of that time is invoked as an explanation for the nuclear waste management challenge. DECC, for instance, wrote, “the UK has accumulated a legacy of higher activity wastes and material” (DECC, 2014a: 12). The notion of ‘legacy’ plays an important role in narratives of the UK’s nuclear pasts and presents. Through the idea of ‘legacy’ UK disposal culture frames the UK’s nuclear past in a positive light. Rather than a problem, the notion of legacy transforms the unruly and hazardous nuclear wastes and sludges in storage ponds and silos into remnants of a glorious nuclear past.

The NDA connects legacy wastes with exhilarating notions invention and exploration by describing the UK nuclear industry as having been shaped by the "heady atmosphere of scientific discovery" of the early years of the UK nuclear industry (NDA, 2016). Nuclear waste in the NDA's account, thus, is as much a creation and a legacy of science and scientific progress. While Sellafield is described as "the home of some of the most hazardous nuclear facilities in the country" (Sellafield Ltd., 2015a: 37), the NDA underlines the 'uniqueness' of Sellafield as a site "where many major developments in the 20th century nuclear industry were pioneered" (ibid.). Instead of reflection, the UK disposal culture has reclaimed the complexity and hazardousness of the nuclear waste problem and posited itself as an "an example to the rest of the world" (HMG, 2013: 6) in nuclear waste management. As in the first half of the 20th century, Sellafield is presented as "pioneering the future" once again (Sellafield Ltd., 2015a: 3) as the UK disposal culture lays claim to the ability to manage the uncertainty, complexity and mess. Simultaneously, the historical negligence of waste is romanticised. Paul Nichol, Head of the Pile Fuel Storage Pond at Sellafield has noted

> There's a real sense of history about the place. We've all seen the lovely old photos of the pond being built and it really engenders a sense of pride. The nuclear pioneers who designed and built the pond didn't have any blueprints to copy and worked to unbelievable short timescales. (quoted in Sellafield Ltd., 2015b)

He went onto state how the workforce at Sellafield "has recaptured some of this old pioneering spirit, and are coming up with all sorts of innovative solutions for the incredibly difficult job we're faced with cleaning-up Sellafield" (ibid.). The emphasis on the pioneering spirit together with contemporary plans for nuclear new build normalises and invisibilises waste. Rather than raising waste as genuine a matter of concern, and a means to open up debate about nuclear power, the UK's continuing infatuation with nuclear technology naturalises waste as an uncritical extension of the industry. Rather than a problem, waste provides business opportunities. The narrative of nuclear as a climate change mitigator (e.g. DECC, 2014b) is much stronger than the concerns over waste management. In the UK's nuclear future making, then, nuclear waste continues to be trumped by the promise of nuclear power of better futures.

Visibilising waste

During one of our chats Jodie, a PhD researcher whose project I followed and meddled with in the UK lab during my fieldwork mused,

> "The UK has been a leader in the field for generating nuclear energy. So, why aren't they leading the field in the disposal of nuclear waste?"
>
> "Yeah, why?", I wondered too. (Jodie, interview)

Establishing a nuclear industry and maintaining the UK's position as leading a nuclear actor were, for the UK government, priorities, critical practices and matters of care (Puig de la Bellacasa, 2017). To pursue matters of care is to affect and be affected by the matters at stake (Michael, 2017). While care for the AGR enabled the construction of a whole fleet of reactors and maintained the UK as a leading nuclear country for a while, the narrow attention on reactor development led to the unfolding of a long-term nuclear future and emergence of nuclear materials that forced the establishment to intervene, to actively reclaim responsibility of what had emerged through the negligence of nuclear matters. Care for reactor development can here be read as an active selective mode of doing by the UK nuclear establishment. Focus on reactor development invisibilised other concerns and focused the industry's energies to a pursuit of a narrow, short(er)-term future. Beginning from the late 1950s the UK's nuclear industry focused on the development of reactor designs, while waste materials were left in storage ponds at Sellafield without plans for their retrieval and disposal in the future. The industry's attention was on improving nuclear reactor and fuel technology, not looking after the by-products of the industry. Although the nuclear future was envisioned through 'a long-term carefully balanced nuclear programme', as we saw earlier, the focus of the UK's nuclear establishment was on the short-term technoscientific future of reactors. Longer-term consequences weighed little in this future making. What was at stake was national technoscientific and political prestige on an international stage. Although 1959 saw the publication of the first review of nuclear waste management titled *The Control of Radioactive Wastes*, nuclear waste, as we saw – and as the title of the review seems to imply – was considered manageable and controllable. Commenting on the review, Lord Shackleton reflected that it was “clear” that nuclear waste disposal “is a subject that will have to be kept under continuing review” and noted that the review was an “admirable beginning” (HoL, 1959, vol. 219, c. 902) for nuclear waste management in the UK. Yet, the ‘admirable beginning’ did not see any follow-ups until the 1976 Flowers Report, by which point the waste management situation had corroded from a state of manageability to alarming. The materials had been siting in the ponds long enough to have formed sludges (a kind of radioavtive mud), which rendered waste management more complex, hazardous and expensive than it would have otherwise been.

Nuclear waste, sludges and murk offer us a classic case of *Frankensteinian* creation (Latour, 2011b). In *Love Your Monsters*, Latour argues ‘we must care for our technologies as we do for our children’. Contemporary societies’ gravest sin, he contends, is not that we have created particular technologies, but that we have abandoned them to themselves and “have failed to love and care for them” (ibid.: 20). Instead of taking responsibility for the becomings of technologies, societies ascribe their sins to technologies, to their creations. To understand and assume responsibility for the becomings of technology, Latour posits, societies must modernise modernisation. We need to overcome the boundary between the social and the technical and switch “the modernist notion of modernity” for what Latour labels a “compositionist” notion of modernity (ibid.) that allows us to see human development as becoming-with (Haraway, 2016) a range of nonhumans and to appreciate that interdependency as *an essential condition* to the existence of heterogeneous beings (Puig de la Bellacasa, 2017).

The initial representation of nuclear waste through its chemistry rather than nuclearity (section 4.4) posited waste matter as something manageable, as a matter of fact (Latour, 2004). The matter of factness of waste closed down and denied its liveliness and vitality. The removal of nuclearity and the belittling of hazardousness of nuclear waste created an imagination of nuclear waste that could be ‘kept under review’, but that did not need immediate care or active intervention. Rendered passive, nuclear waste did not demand any action. The pacification of waste justified its abandonment in storage facilities, but it also meant the UK nuclear establishment paid little attention to the effects and consequences of its doings. The establishment care for nuclear power technology, but not its by-products.

The claimed manageability of nuclear waste allowed the industry to focus on developing the industry. By ignoring the vitality of waste matters, the UK nuclear establishment could busy itself with caring for the vitality of the industry. Meanwhile, a mud-like substance emerged in the depths of Sellafield’s open-air storage ponds through encounters between neglected waste matters and their environment. The emergent substance, sludge, is an “*unplanned* by-product” of nuclear activities (Sellafield Ltd., 2017, my emphasis). It is a result of interactions between algae, decaying spent nuclear fuel or waste, wind-blown materials (the ponds are open to air) and forms of debris. Its “radiological composition, its texture and weight” differ based on the wastes stored in the ponds where sludges have been forming for up to 65 years. Sludge, like nuclear waste, is many. Each variation of sludge needs its own bespoke retrieval, treatment and storage processes (Sellafield Ltd., 2015a: 44). Most of the radiological hazard at Sellafield lies at the bottom of storage ponds that continue to house waste and sludge – or a “complete mess” as Christopher, a PhD student, working in the UK lab noted. Cleaning up this mess, classifying nuclear waste as a problem, decisions on “how to manage this waste in the long term” as a way of “planning for our future” (Defra, 2001: 7) are different interventions in the waste’s *status quo*. These practices of classification and cleaning up are transformative doings that aim to deliver Sellafield to a safe end state and emplace waste underground. Interventions, such as cleaning, in the becoming of sludge have transformed waste into a matter of care (Puig de la Bellacasa, 2017).

As matters of care, nuclear waste and sludge demand action. Matters of care is a Puig de la Bellacasa’s reworking of matters of concern (Latour, 2004). While both care and concern connote affective and ethical worry, care has a stronger sense of commitment. Where concern contains thoughtfulness, it lacks a notion of *doing* that care denotes. Caring is the everyday doings of maintenance and repair, and a way for ‘us’ to remain responsible for the becomings of things. The negligence of nuclear waste next to the prioritised development of reactor technologies in the UK underscores the notion of care as a selective mode of attention and an active exclusionary material doing. Care for nuclear things focused on and cherished energy generation and reactor technology, and in the process excluded waste that was left in storage pools and facilities for decades to form new and more complex beings, and to lead to a situation where there is no choice but to act. Colin, a CoRWM member, noted

> There has to be a better way of getting radioactive murk out of legacy ponds and silos [at Sellafield] than the way they are embarking on doing it. But they don’t have the luxury of sitting there for 15 years while somebody comes up with that better way. So they’re doing it, because it’s more important to get it done than to wait for a better solution in 20 years time. If you had the 20 years to wait, you might well be able to do it better later. But you don’t, because the bloody buildings are in a mess. (CoRWM member, interview)

There is urgency at Sellafield in the present. Past future making has created a ‘mess’ that needs urgent attention now. Still, this waste has attracted attention only after it has, through local encounters, morphed into matter that has corrosive messy effects on its immediate surroundings. Sludge, as the hazardous effect of these encounters, has raised alarm to intervene, to do something. Yet, urgency is not an emergency. Urgency has a different temporality (Haraway, 2016). Emergencies, Haraway writes, connote the apocalyptic and the mythological, while urgencies are part of our times. Urgencies are the present, the times when we must think and do; when we must intervene in the ongoing material remakings of the world. Matt, a UK Professor of Nuclear Materials, noted that in his dealings with the UK government, “the first thing to be chopped when money is tight [is] waste management, because […] we can deal with that later”. On the governmental level, despite the government’s commitment to GD as the long-term management option for nuclear waste, waste itself does not give rise to the kind of urgency that would prompt financial security for the UK's GD project to cover the tasks academics or the industry see necessary. Matt contended that this might be costly for the GD project.

> One of the barriers to achieving […] geological disposal in the future is repeating the mistakes of the past that basically say that's tomorrow's problem. (Professor of Nuclear Materials, interview)

The government's postponement of the waste management to the future rather than actively engaging with in the present implies a failure to appreciate the complexity of the problem, and the time it takes to implement GD (see also section 6.2 and 6.3).

Nuclear waste brings "us face to face with a social, emotional, ethical, political and environmental situation at the heart of which lies the security of the living world" (Massart, 2013: 451). Nuclear waste management is about maintaining a 'degree of liveability' (Puig de la Bellacasa, 2017) in the world. As such nuclear waste management is a practice of caring. Caring conceptualised as *everything we do* (Tronto, 1993) is not a moral position but selective attention. Understood as doing, care needs a focus. Here, I have proposed that the UK nuclear establishment has and continues to focus on nuclear power rather than nuclear waste. The urgency experienced at Sellafield has not resulted in a re-evaluation of the UK's nuclear policy. This urgency combined with the continuing faith in the promise of nuclear prioritises the present over the future. The urgency at Sellafield is about managing and maintaining the site now, while nuclear new build is more likely to benefit the present rather than the future. While "those who generate the wastes should take responsibility, and provide the resources, for the management of [waste] materials" (OECD, n.a.) in a way that will not impose burdens on future generations, the decision to commit to nuclear new build, despite the waste it will generate, skews that responsibility by imposing more nuclear waste on the future.

In *Theses for the Atomic Age* (1962) Anders extends our ethico-political responsibility in time and calls for 'united generations'. By doing so he argues for the widening of the temporal space of responsibility. The future should be afforded the same respect and care as the present. Anders argues that in the Nuclear Age "the future has already begun […] the distinction between generations of tomorrow and of today has become meaningless" (Anders, 1962: 495). The future and the present, Anders argues, should be subject to the same responsibility. One could ask, then, how can nuclear new build be justified in a situation where the UK still lacks a concrete solution to the nuclear waste problem (see section 6.3)? If the UK has not been able to care for its waste in the past and the present, can it justify generating more waste in the future?

Where Anders imagines care for the future through and with our grandchildren, Adam and Groves posit that people imagine futures through all "the things we […] care about, as life-shaping attachments" (Adam and Groves, 2011: 24). These attachments inject our lives with meaning. When we care about things, we care about their futures. We are invested in their maintenance and their becomings. But how far in time and space can our feelings of responsibility extend? Following Adam and Groves, one can assert that caring about (at least immediate) future generations should come to us fairly easily, yet the question remains can we care about nuclear waste? GD has been harnessed as a supporting argument for the UK's nuclear new build programme. The relationship between GD and nuclear new build has been contested on ethical basis (CoRWM, 2006). While GD has been positioned as an act of taking responsibility, it is still used to justify nuclear future making that appears to prioritise the present. It appears that the promise of clean and cheap electricity through nuclear continues to dominate nuclear future making in the UK – and thus contribute to the ongoing nuclear waste management challenge.

4.7 Summary

In this chapter I first looked at the contemporary nuclear infrastructures and waste inventories in the UK and Finland. Here, a specific note was made of the difference between the scale and complexity of the UK and Finnish nuclear industries. In the following two sections we traced the makings and unmakings of the nuclear waste problem. Again, differences emerged between the two cases. Where the UK waste definitions shifted from manageability to problematisation, in Finland waste management was perceived more as a problem from the beginning, while later on this problematisation shifted to ‘foreign’ wastes. In the final section of this chapter, I speculated about the emergence of the waste problem in the UK through the notion of care – and in particular care as a selective mode of action. Here, I proposed that waste has emerged as a problem through negligence, as the UK’s nuclear establishment was focused on and cared for the development of reactor technology and the maintenance of the UK’s position as the leading nuclear country.

In the following chapter, I will trace the ways in which the safety, containment and the deep future are imagined and made in response to the emergent waste futures that were explored here.

5 MAKING THE DEEP FUTURE

> "That's splendid!" said Moomintroll. "Wonderful news. A cave is much better than a box.”
>
> - Tove Jansson, *Comet in Moominland*

In the previous chapter I looked at some of the past practices and policy decisions that set nuclear waste futures in motion in particular, yet underterministic, ways in the UK and Finland. The present nuclear waste challenges in these countries are partly informed by the complexity of their respective nuclear infrastructures and waste inventories, which have been informed by policy decisions about the status of nuclear materials; whther they wastes or assets (I will pick this discussion up again in chapter 6). The present challenges are also informed by the coupling of waste futures and nuclear presents that have, at least in part, been influenced by understandings of waste’s status not only through the waste/asset binary, but also through shifts in the nuclearity of waste. In Finland, nuclear presents and waste futures have been tied together more strongly from the beginning of the nuclear industry than they have been in the UK. Finnish nuclear operations in the present have been tied to long-term waste management plans through nuclear legislation and regulations. In the UK, in contrast, the initial pacification of waste materials as assets and/or and chemical waste led to a situation where mere oversight of the waste situation was deemed as sufficient waste management.

In this chapter I will explore what kind of responses are envisioned and engineered as solutions to the waste problem traced in the previous chapter. I will examine how safety into the *deep future* is made through relational and situated practices. I will begin by examining how the deep future of GD has become standardised through radionuclide half-lives and international standard practice. I will then explore, first, how the GDF as a *technology of stagnation* aims at slowing down time and processes underground, and second, how claims for safety emerge from the classical juxtaposition of nature and culture; available geological, financial and cultural resources; as well as the existing nuclear waste inventory. In the final two sections of this chapter, I will explore some of the mundane material practices through which the deep future is imagined and enacted in the lab, at the drawing desk and in the field; how time is manipulated to make predictions about the future in the present, and how the containment of nuclear waste is envisioned in deep invisible spaces in the lab.

5.1 Futures uncertain and standardised

Stephen Hawking's vision of the future that we encountered in the introductory chapter of this thesis asks for a generous treatment of uncertainty and the unknowable. For Hawking, embracing, rather than fearing, uncertainty and building a future in spaces beyond knowledge is the only way to ensure human survival. While his vision of space inhabiting humans might, at least for some of us, appear as utopian, it still draws on and from the past. Hawking operationalised the past, such as the Apollo missions, as a form of evidence that his future is do-able (Fujimura, 1987). His vision of an extra-terrestrial human future, like future making more broadly, is reliant on the folding together of pasts, presents and futures (Morton, 2013). The past and present offer resources for imagining and crafting futures. In this respect the deep future of GD is no different, as we will see. What renders both Hawking's vision and GD separate from much of the more short-term technoscientific future making is their vast time horizons.

While Hawking and the international nuclear waste community provide us with radically different spatial imaginations of the future, temporally these imaginations overlap both in the short and the long-term. Where Hawking (2017) envisioned a manned landing on Mars by 2025, the Implementing Geological Disposal Technology Platform (IGD-TP), a technoscientific forum that directs and coordinates European R&D effort in GD, states as its vision that in "2025, the first geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste will be operating safely in Europe" (IGD-TP, 2012: 9). The '2025 vision' in the IGD-TP's own words represents its 'commitment to the future' (IGD-TP, ibid.: 13). IGD-TP has approximately 120 members, including the universities where I conducted my fieldwork. The Platform's membership ranges from academic institutions, research institutes and centres to nuclear waste management organisations. Each member organisation is committed to the 2025 vision. At the moment Posiva in Finland is the most likely candidate to realise this vision. The company aims to begin nuclear waste disposal in Onkalo in the 2020s, which means that disposal would be completed and Onkalo sealed off and closed in the 2120s (Posiva, n.a.c.). The UK, according to present plans will operate its GDF until the late 22nd century (DECC, 2014a). The UK's disposal timeline thus exceeds the one-century mark Hawking (2017) has given humanity to flee Earth in order to survive the next million years.

Those next one million years are an epistemic and engineering challenge for GD projects. Nuclear waste is an inevitable product of the nuclear fuel cycle, and nuclear power generation. The core of a nuclear reactor consists of several hundreds of nuclear fuel elements. With time the concentration of fission products and heavy elements in the fuel increase to the extent that it becomes impractical to continue to use that fuel. Therefore the 'spent' fuel is removed from the reactor after 18-36 months, depending on reactor design, to maintain efficient reactor performance. When removed from the reactor, spent fuel emits high levels of radiation and heat. Spent fuel elements are placed in storage pools to allow both heat and radiation levels to decrease. The elements stay in the pools from several months to several decades, with the pool water acting as coolant and protective radiation barrier. As we saw in the previous chapter, spent fuel can either be treated as waste or an asset. If it is treated as an asset, spent fuel is reprocessed in order to extract the uranium and plutonium it contains for reuse. Regardless of whether spent fuel is treated as a waste or an asset, it still needs to be stored to allow for radioactive decay – the natural decrease of radiation in nuclear materials. Fission products in spent fuel have finite lifespans and the term 'half-life' is used in nuclear physics to describe how quickly an atom undergoes radioactive decay and how quickly the level of radioactivity in that material gets halved.

The challenge with GD stems from the slowness of radioactive decay. While some radionuclides have minute half-lives, others, as we saw in the Introduction, are so long-lived that they have been mobilised to calculate the age of Earth. Where the presence of uranium in the Earth's crust "reveals a story millions of years in the telling" (Irvine, 2017), GD writes a new chapter to that story by reintroducing long-lived nuclear waste to the Earth's crust. These wastes are much more radioactive and hazardous than the original uranium ore. High level waste resulting from reprocessing retains dangerously high-levels of radioactivity for approximately 10,000 years, while some fission products present in spent fuel are much more long lived. Van Luik of the US Department of Energy, explains that some of the actinides in spent fuel "are generally very slow to radioactively decay into smaller atoms – which then decay more rapidly – and some of the actinides actually do remain hazardous for a million years and beyond. The trick is to isolate them for that length of time" (in Manaugh and Twilley, 2012: 228). The slowness with which the radioactive threat of nuclear waste decays, and the resulting need to isolate waste for as long as they pose risks to the lived environment, is the main challenge for engineering safe disposal.

The one million years van Luik mentions above has become cemented as an internationally accepted and standardised timeframe for GD safety assessment. A precursory exploration of the OECD *The Safety Case for Deep Geological Disposal of Radioactive Waste: 2013 State of the Art* document confirms as much. The majority of countries in the process of implementing GD seek to establish the safety of their GDFs over a million-year assessment period (OECD, 2014: 49, 104, 132). In its 2012 Safety Case[10], Posiva, the Finnish GD implementing organisation, notes how in its Safety Case an assessment "time frame of up to one million years into the future is considered", this "is consistent with other assessments of spent nuclear fuel disposal internationally" (Posiva, 2012: 13). Spent fuel, Posiva continues, must be contained as long as it can significantly harm the surface environment, the normal habitats of humans, animals and plants. The level of harmlessness is achieved at "one million years [when] the activity of the spent nuclear fuel is similar to that of the original uranium ore from which the fuel was fabricated" (ibid.: 13-14). The uranium ore found in nature is largely considered safe for humans and other living entities to be around. Accordingly, the threat posed by spent fuel and high level waste is assessed in relation to and against the radioactivity levels of natural uranium ore (OECD, 2009). Once the radioactivity of spent fuel and high level waste has

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[10] The International Atomic Energy Agency (IAEA) defines the safety case as a suite of "scientific, technical, administrative and managerial arguments and evidence in support of the safety of a disposal facility" (IAEA, 2012: 1).

decayed to these levels, they are no longer considered dangerous. Thus to be classified as ‘safe’, nuclear waste must revert back to ‘historical’ levels of radiation (present in the original uranium ore) in the future, but this process, as I have noted, is extremely slow.

While the million-year timeframe for safety assessment has become part of international standard practice, the establishment of the million-year standard has not been uncontroversial. In a 2011 interview, Peter Galison, a historian of science and a filmmaker, described the million years as “absurdly distant” (in Kruse, 2011), while a retired Posiva Advisor, Ilkka, held that “this kind of million-year time perspective isn’t part of engineering sciences”. Matti, a researcher at the VTT Technical Research Centre of Finland (VTT), echoed Ilkka closely and observed that the timeframe of GD safety assessments forces science and engineering out of their comfort zone. Researching the behaviour of the waste canister in which spent fuel will be disposed of, he noted

> normally, when assessing the lifespan of metals you shouldn’t extrapolate by more than a factor of three. Here we are doing it by a factor of hundred, so we go beyond technical norms and recommendations. So [time] is a technical challenge. (VTT Researcher, interview)

This deep future of GD created by radionuclide half-lives and international standard practice and enacted through GD safety assessments challenges human ability to know the future. The million-year timeframe slides beyond knowledge. Rodney Ewing, a Professor in Nuclear Security at Stanford University, has argued, much in line with his Finnish colleagues above, that the million-year timeframe requires “scientists and engineers to complete an analysis that is at its best opaque and at its worst not believable” (Ewing, 2011: 13). Mapping and making sense of deep future requires what Adams, Murphy and Clarke (2009) describe as the substitution of the ‘sciences of the actual’ by prediction and speculation. A Posiva Project Manager, Aila, weighed the challenge imposed by the deep one million year future of GD on knowledge production.

> It’s one million years. Of course, we can’t predict [it] exactly. We can’t predict tomorrow’s weather, so we have to be very humble. […] When we talk about one million years, you have to trust. Nobody can tell you right or wrong. This is right, that’s wrong and he’s bullshitting you. There is no way to know, so you have to trust. Some sort of faith-type of thing. Is there a god? Isn’t there a god? Nobody can tell. (Posiva Project Manager, interview)

Here, Aila describes the deep future as essentially unknowable. The future escapes certainty. It is unpredictable. Rather than a matter of ‘science of the actual’, making safety into the deep future is portrayed by Aila almost as a religious matter. GD is an uncertain human intervention into an uncertain future. Predictions and knowledge claims about deep future and the safety of the GDF are empirically unverifiable (Bergmans and Schröder, 2012). Rather than accurate knowledge, the making of safety relies on trust in the disposal system and available methods of knowledge production. Uncertainties, Arthur, a RWM Research Manager noted, “are a huge point for discussion over geological disposal”. He went on to divide the level of uncertainties temporally.

> If you look at the first 10,000 years, I think uncertainties are quite well dealt with in that the engineered barriers are providing a very robust process, radioactive decay is happening. […] Geological uncertainty obviously, as you get past a million years, it becomes greater. (RWM Research Manager, interview)

The million-year timeframe thus forces disposal cultures to look to time of increasing uncertainty. The timeframe turns the gaze of disposal cultures to times when the presence of the human species is uncertain. Future generations might evolve in ways that they no longer resemble humans of today. They might not even be the same species. Or it might be that they and other beings cease to inhabit the planet during the million years GD safety assessments seek to address. With one million years, we “are talking not only about the possibility of political, linguistic, material processes, but biological evolutionary processes undergoing great changes” (Galison in Kruse, 2011). The deep future and GD do not, thus, just challenge knowledge making practices, but also understandings of what it means or might mean to be human; what it means to live in the world; and what counts as the ethical object of protection. The very distant future of GD thus raises both epistemological and ontological challenges and questions in the present. In a spatial sense too GD pushes knowledge towards the unknown. The deeper the GD projects extend in space, the less data there is about present geological conditions. Uncertainty about geological conditions increases at depth (RWM, 2016b). In part this is because “the most accurate predictions near [the surface] are facilitated by the proximity to the surface, and consequent availability of […] data” (Nordbäck and Engström, 2016: 96). Conversely, existing alternative or complimentary geological data produced by the mining industry, for instance, might not be available or appropriate to make judgements about the suitability of geological conditions for GD purposes. Since geological data at depth is scarcer, the ability to predict disposal conditions decreases not only with time, but also in space. The deeper scientists seek to map the future spatiotemporally, the less certainty there is about the reliability of the knowledge produced and knowledge production tools.

Despite its futurity, the deep future is the stuff of technopolitical work in the present. It poses major challenges for GD projects in the present, but it is also viewed as an object of protection and as such has affective power in and over the present. The deep future is unknowable, and while GD projects seek to map and render that future predictable, GD itself is a project through which that unknowable future is being crafted and configured. Where the slowness of radioactive decay expands beyond technoscientific practices of knowledge production, the envisioned need to protect life from radiation in the very long-term drives the construction of disposal facilities underground in spaces that are expected to be unreachable and unknowable to future generations.

GD, then, asks societies to act upon a future that is and remains inevitably uncertain and out of reach. It is little wonder that representatives of STUK, the Finnish regulator, and Posiva described GD decision-making through notions of ‘bravery’ and the ‘need to have guts’. GD, as ethico-political doing, seeks to extend the security and safety of the living world to the deep post-human future, while simultaneously seeking to postpone the arrival of a future without humans. GD asks disposal cultures to predict the unpredictable and to protect times and beings present generations do not, cannot and will not know. GD asks geological sciences to evolve from historical sciences into predictive ones, to turn their gaze from mapping the unfolding of Earth's history into the unfolding of the distant future. It binds together timeframes that are radically different yet equally relevant. Even if it cannot be fully known, the deep future needs to be known well *enough* in the present to plan for its protection. To render the deep future predictable and safe enough, it is enacted and made in the field, the lab and in public documents through particular sociotechnical doings and relatings. In what follows, I explore some of those doings and relatings, in the first instance, I trace some of the ways in which geology and available geological conditions have been mobilised in making safety into the deep future. Here, the focus will be more heavily on the Finnish case. In section 5.4, I will trace some of the ways in which the deep future was made and encountered in the UK lab.

5.2 Making safety underground

Bedrock has been posited as the guarantor of long-term safety in GD (Nikula et al., 2012). It is the final barrier of the multi-barrier concept that is envisioned to isolate nuclear waste deep into the future. Even those in the nuclear waste community who are more sceptical about GD and its ability to provide safety in the very long term agree that geology has an important role to play in the containment of nuclear waste. William, a former member or CoRWM, held

> The best thing is to put [nuclear waste] back into the Earth's crust where the [uranium] came from in the first place. It's pretty well agreed that some form of geological disposal is the best answer and nobody has seriously questioned that. (Former CoRWM member, interview)

The role of geology in providing long-term safety is broadly accepted. Geology is positioned as the medium that can match and mediate the half-lives of radionuclides. The deep future envisioned through GD, William noted, is a mere "drop in the ocean compared to the age of the Earth". Arthur, a RWM Research Manager, similarly noted how in the long run the engineered barrier system

(EBS) is no match to the longevity of radionuclide half-lives. This leaves the geological environment as the main barrier. Arthur noted how

> The radiological impact of uranium in a GDF sense doesn't actually increase till you get up to about half a million years, [when] you're beyond the point when engineered barriers provide you with much integrity. You're actually relying on the geological barrier. (RWM Research Manager, interview)

No human construction could survive for the timeframe necessary for the isolation of nuclear waste, but geology has the ability and capacity to contain waste for much longer than any human made system independently could.

Geology, then, is "the ultimate barrier" as a Finnish PhD student Samuli phrased it. No single type of geology has been posited as the 'best' for GD, yet there is "widespread international agreement on the types of rock that may provide a suitable […] host [environment] for the GDF for many years" (RWM, 2016a: 6). In the latest iteration of its Generic Safety Case for the GDF, RWM lists three rock types that have been considered suitable for GD internationally, and that could thus be considered as host environments for the UK's GDF. These include higher strength rocks (for example, granite), lower strength sedimentary rocks (for example, clay), and evaporite rocks (for example, halite). Each of these rock types has its strengths and weaknesses. Higher strength rocks have low porosity and low permeability, which means that groundwater flow in these rocks is low. Similarly, lower strength rocks are characterised by low permeability, while evaporate rocks provide a dry disposal environment. On the other hand, higher strength rocks have fractures in which groundwater can freely flow, while lower strength rocks can have significant quantities of water in their pores (RWM, 2016a).

The GDF can thus be constructed in a range of geological environments. In the absence of a disposal site, the UK is "fairly unique" as it has developed a "totally generic safety case" (Bailey, 2015: 1634). As the UK has a range of potential geological settings that could host a GDF, RWM has developed three illustrative disposal concepts, one for each of the rock types mentioned above in its Generic Safety Case. These concepts “tell the ‘safety story’, i.e. how safety is achieved for each of the illustrative concepts” (ibid.: 1640). However, since the UK lacks a disposal site safety remains more solidly in the realm of stories and ideas (Adam and Groves, 2007) than it does in countries that have already chosen their disposal sites. Yet even where disposal sites exist, safety arguments are not set in stone in a straightforward manner. Rather, they are made through situated and relational practices.

Relational makings of safety

Safety is not an inherent attribute of the GDF. Those involved in the GD projects like to point to the broad international consensus or “general agreement […] that geological disposal provides the safest long-term management solution for higher-activity waste” (RWM, 2016b). The argument presented in this chapter is that safety emerges through relational makings. Rather than the safest, GD should be conceptualised as the *least worst* solution available (Corkhill, 2017) or a *safer than* waste management alternative. Relational makings of safety are based on binaries separating the human and the nonhuman; the underground and the aboveground, disposal and storage, nature and culture. In what follows I will explore how these binaries have been mobilised by the Finnish disposal culture to make the case for the safety of GD in the very long-term.

GD envisions a future underground. A deep future that is unreachable to and undisturbed by future generations. Going underground can be seen as a practice of ‘world-reduction’. Fredric Jameson posits that moving from the surface to the underground is “systemic exclusion […] in which the sheer teeming multiplicity of what exists, of what we call reality, is deliberately thinned and weeded out through an operation of radical abstraction and simplification” (Jameson, 1975: 223). Jameson’s description falls in line with the logic of passive safety, and with the supporting argumentation made for GD. Passive safety following the closure of the GDF effectively means the end of human intervention and management in the facility. Passive safety, the IAEA holds “means that the disposal facility, with its associated radiological hazard, is no longer under active control. It is the performance of the natural and engineered barriers that provides safety after closure” (IAEA, 2011: 22). In a very clear sense, then, safety in the very long-term is delegated to the EBS and the bedrock. Humans, and the surface environment more broadly, are seen as less predictable and more changeable than the underground. By extension, human ability to manage waste aboveground is considered more uncertain than the ability of the GDF to contain waste until it has decayed to safe levels.

Rabbe, a researcher at the Finnish Geological Survey (GTK), positioned recent European history against the deep future of nuclear waste, and noted that guaranteeing human control over nuclear waste for the necessary timeframe is questionable.

> If we talk about a few hundred years, what Europe and national borders were like, and everything that has happened, it doesn't sound reasonable to me to leave wastes [on the surface]. Who knows how long Finland or Posiva will exist? (GTK Researcher, interview)

Societal ruptures and discontinuities aboveground are considered as a safety risk. They are viewed against the perceived continuity and predictability of the underground. RWM posits in a document titled *Methods for Management and Quantification of Uncertainty* how

> There is substantially more uncertainty over the future of society than there is over whether the geosphere will perform its desired role of isolating the waste from such future societies. This is reflected in the relative timescales of geological change versus social change. (RWM, 2017: 26)

The safety of the GD is articulated through the different temporalities of the aboveground and underground, the human and the geological. The slowness of geological processes, posited in opposition to the shorter span of social change, is at the root of visions of long-term safety deep into the future.

Safety is crafted and seen as the function of the relative passage of time. Matt, a Nuclear Materials Professor, held there is "really good scientific evidence that in some geological formations the natural construction of the host rock and setting is going to provide the containment we need for the time we need it". Containment then, despite the notion of GD as the 'end point' for nuclear waste, in this description is not expected to last forever. Nonetheless, the underground, unlike the aboveground, is assigned the ability to provide containment deep and long *enough* into the future. Because of the slowness and length of geological processes, the underground is constructed as a safe space. Shapiro (1997) observed similar kind of relational deep time world-making in the writings of Aldo Leopold, an American philosopher and ecologist. Leopold, according to Shapiro, "was careful to differentiate between the earth and humans, arguing that the earth was considerably less alive in degree, but considerably more alive in time and space" (Shapiro, 1997: 106). The making of safety into the deep future, as I have begun to trace, relies on corresponding distinctions between the liveliness of the aboveground and the underground. These distinctions between the degrees of liveliness of different spaces in time are at core of arguments positing the underground as *safer than* the aboveground.

In imaginations of the underground "the defining characteristic of the subterranean", Rosalind Williams writes, "is the exclusion of nature [yet] what is most simplified is not nature but humanity" (ibid.: 20-1). While Williams does not discuss GD, her observation is relevant here. The GDF will be a highly engineered and highly technical space, yet the underground is envisioned by the international nuclear waste community as a space undisturbed by humans and human time. As we will see further below, the 'world reducing' move to the underground does not do away with uncertainty or the complexity of the world. The underground itself is a contested space. Nonetheless, it is constructed as safer and simpler than the aboveground world. The greatest erasure in the move underground is the envisioned exclusion of the human. Nikula et al. observe that GD "seeks protection for humans and from humans" (Nikula et al., 2012: 166). The move underground simplifies humanity into that which needs protection from hazardous nuclear waste, but also into that which may through accidental or deliberate intrusion into the GDF jeopardise the safety provided by GD. GD projects do not assign humans with an active role in the maintenance of safety (Schröder, 2016). Rather than a space for human meddling the underground is a space where humans are not welcome. The international nuclear waste community envisions it as a non-human, and ultimately, post-human space.

The underground is a reduced world where time and processes slow down. The slowness of process promises a stable – and by extension a safe – disposal environment. Jukka, a Finnish nuclear consultant held that the "very slow groundwater flow [is] probably the biggest [safety] factor", while RWM write of a "considerable confidence that a well-chosen geological site will be relatively stable for a very long time into the future and provide effective containment of the radioactive material" (RWM, 2017: 26). The pace of geological movements and events are juxtaposed with potential events aboveground in support of claims about predictability, and the safety of GD in the long-term.

> Leaving the [waste] on the surface is unreasonable. When they are on the surface, they are a real risk. The idea of the disposal concept is that they don't have to be minded, taken care of, managed. Even if [the waste] were just dumped at the end of some tunnel, it'd always be a better solution that just leaving them aboveground. (GTK Researcher, interview)

Underground nuclear waste poses less of a risk to the aboveground, thus the underground is delegated the management of nuclear waste. The notion of greater underground safety is not argued only in relation to the perceived uncertainties and discontinuities of human societies, but also in relation to broader climatic and environmental processes occurring aboveground. "By placing the waste underground", RWM write, waste "will be protected in the event of earthquakes, tsunamis and environmental change" (RWM, 2016b: 3). Ruptures aboveground are seen as a risk to the safe long-term management of nuclear waste. Eero, a Principal Researcher at VTT noted, how "the laws of nature govern everywhere", but aboveground "conditions vary much more. Ice ages come and go. They don't affect the bedrock that much apart from minor seismic activity at the edge of the ice sheet. The effects of glaciation are much greater aboveground" (see Figure 10). The underground is essentially envisioned as the protector of waste from the uncertainties of the aboveground.

It is through contrasting and comparing the underground to the aboveground that the safety of GD emerges. In its 2012 Safety Case, Posiva describes how

> An appropriately chosen geological formation provides an environment that is *stable* over many millions of years – geological timescales – and *the nature of changes that can occur is predictable* from the geological sciences. (Posiva, 2012: 34, my emphasis)

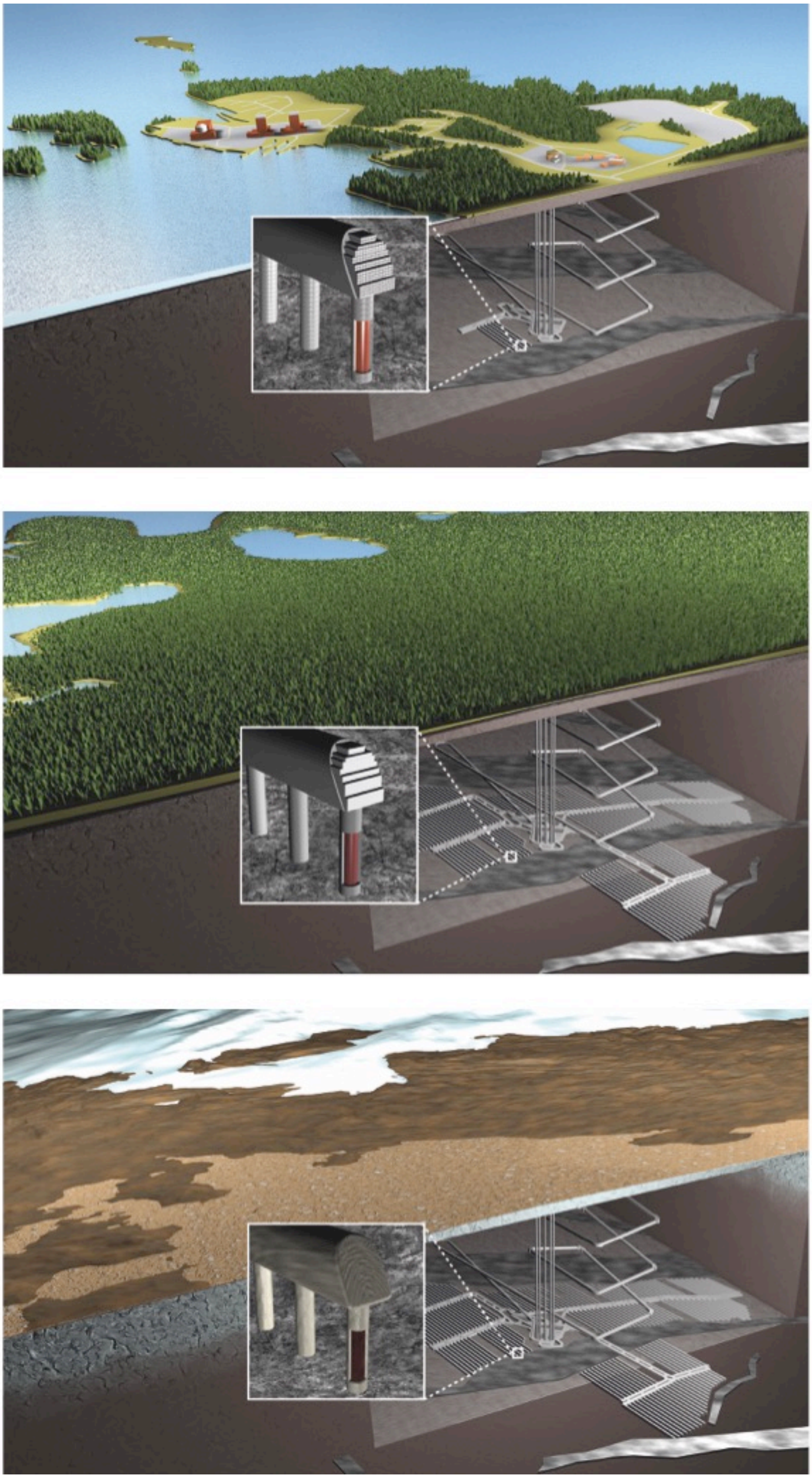

Figure 10. Posiva’s vision of the evolution of aboveground and underground spaces from the 2020s to the next glaciation. Courtesy of Posiva Oy.

The safety of GD is made through relational doings that set the aboveground in opposition to the underground. The aboveground is crafted as inherently more unpredictable space as recent human history is mobilised to demonstrate the fracturing of social order and the significant repercussions this has had on the reordering of Europe. On the other hand, the predictability of unpredictable environmental disruptions and discontinuities, such as tsunamis or earthquakes, and more predictable disruptions, such as glaciations, are mobilised to underline the uncertainties or instabilities of safety aboveground. In contrast, the underground is envisioned as an undisturbed, predictable and stable space – and as such much safer than the aboveground deep into the future. The reduced world of the underground isolates the waste from the more complex and unpredictable surface world.

The underground offers two-way protection. It protects the aboveground from the waste, and the waste from the aboveground. Jukka viewed that a key "safety factor probably is that underground the wastes are so unreachable compared to […] storage". Where storage requires active intervention, delegating care work to the underground removes the need to discipline humans to mind and be mindful of nuclear waste. In a sense, then, safety is posited as the luxury of human ignorance to the consequences of the Nuclear Age. Matt weighed that

> In the end safety means that you can bury this radioactive waste in these facilities all the way into the ground, and life carries on on the surface. All the living systems that exist in proximity continue to exist without being impacted. (Professor of Nuclear Materials, interview).

The 'unprecedented split future' (Masco, 2006) introduced by nuclear technology, the balancing act between progress and prosperity on one side, and destruction and calamity on the other, thus, continues into the deep future through nuclear waste management. The split between the human and the nonhuman, the aboveground and the underground is envisioned as the most likely guarantor of safety and protection into the very distant future. Yet, the underground itself – although positioned as *safer than* – is not an uncontested space. Where we often think of rocks and the bedrock as 'hard stuff', in GD safety making they emerge as malleable and open to interpretative flexibility (Bijker and Pinch, 2012). It is this malleability of the bedrock that I will turn to now.

Spaces of risk and predictability

The siting of a GDF and the making of long-term geological safety are in some ways driven by absences. The aim of the siting process is to find the most banal, uninteresting and homogeneous geological environment possible. Important safety considerations include the presence (or absence) of minerals and other resources that may attract future generations and "affect the likelihood of future civilisations inadvertently drilling or mining their way into the waste" (RWM, 2016b: 14). Thus the argument is that the less resources present in the bedrock, the less likely human intrusion into the GDF will be. The main safety consideration, however, is the presence and movement of groundwater. The low potential for groundwater movement "is one of the main factors used in identifying potentially suitable host rocks" (ibid.). Groundwater threatens safety by eroding and corroding the EBS, while also offering transportation routes for nuclear waste away from the GDF. Containment and safety into the deep future are equally about the containment of groundwater flow as it is about containing nuclear waste.

In its *Providing Information on Geology* document, RWM lists the potential for the presence and movement of groundwater in the three broad rock types it considers as potential host environments for the UK GDF. Evaporites offer a dry disposal environment and furthermore they are structurally weak. Any fractures that could form and conduct groundwater in the bedrock will self-heal and close by themselves. Lower strength rocks, such as clay, similarly are weak and cannot sustain fractures that might allow for the movement of groundwater. Instead, any potential movement of groundwater or radionuclides happens through diffusion – meaning there is no through flow of water in the bedrock and the rate of groundwater movement in lower strength rocks is slow. Matt explained how "clay is a very impervious barrier; it takes a long time for water to get in and it takes a long time for things to fuse out". Ulla, a researcher at a Finnish university, noted that a number of disposal programmes, including those in France and Switzerland "have moved from crystalline bedrock towards clay formations", because of clay's containment capability. William further posited that (partly) because of clay "the French have got a better system" than "the Swedish-Finnish hard rock concept". Both Sweden and Finland are constructing their GDFs in the Fennoscandian shield that is tectonically stable and composed of granites, that is, higher strength rocks. Unlike clay, granite is mechanically strong and "suitable for the excavation of self-supporting tunnels and other underground openings, such as deposition holes, technical rooms and shafts" (Posiva, 2012: 32). The strength of rock might ease underground excavation, but it also implies a presence of fractures in the bedrock. Unlike in clay, fractures in granites are unable to seal themselves.

As spaces for groundwater, rock and radionuclide movement, fractures can pose risks to safety in the future. They present spaces where alternative futures can leak into existence. Fractures, then, can be considered as *spaces of risk*. As spaces of risk they impose boundary conditions for the layout of the GDF. In this sense too risk guides the making of safety. While the aboveground is seen as a riskier space than the underground, the underground is not a homogeneous space. Even here some spaces are riskier than others. In their 2012 safety case, Posiva term fractures and fault zones in the bedrock as GDF 'layout determining features' (LDFs). The "presence of deformation and fractured zones", Posiva write, is a key constraint for the design of Onkalo and an important consideration "in the assessments of long-term performance and safety" (Posiva, 2012: 6). The presence of faults and fractures informs the location of deposition tunnels and holes. They guide where waste can go underground. Fractures are not just conduits of unwanted movement, but can also be sources of uncertainty and unpredictability. Van Luik of the US DoE has posited that "the older the granites are, the more fractured they are, and [wate management organisations] can't predict a million years into the future where the fracture zones are going to be" (in Manaugh and Twilley, 2012: 228). The presence of fractures, van Luik claims, throws the long-term integrity and stability of the bedrock into question. Future fracturing can be unpredictable, and, as spaces of unwanted movement and uncertain evolution of geological conditions, fractures can be conceptualised as risky spaces. However, fractures are more ambiguous than 'simple' spaces of risk. In the first instance, it is worth noting that space of risk can be construed in different ways. For van Luik the mere presence of fractures is a risk. Fractures could lead to a loss of containment and safety because they introduce uncertainty to the bedrock conditions, particularly in the very long-term. If future fracturing is unpredictable, there is always the possibility that the GDF is constructed in a body of granite that might suffer fracturing in the future. Posiva, in contrast, argues that fractures are risky not because they are unpredictable, but exactly because it can be anticipated with reasonable certainty that unwanted groundwater and radionuclide movement will take place in these fractures.

As such, fractures can and have been mobilised also as, what I term, *spaces of predictability* by the Finnish disposal culture. The Finnish siting process, that started in 1983 and culminated in 2001 when Olkiluoto was ratified as the disposal site, was guided by fractures and fracture networks. Rabbe, at GTK, pointed out how the past two billion years have produced so many cracks, fractures and fault lines in the Finnish bedrock that

> from a physics perspective there’s no need to create any more, since there are all these alternatives through which energy can be released. *This is the whole basis of the concept*. During the siting process we identified bedrock blocks with clear boundaries into which any rock and groundwater movement would and will be channelled. (GTK researcher, interview, my emphasis)

So whereas van Luik poses the age and fractures in granites as risks, Rabbe sees them as safety factors. In this way the Finnish disposal culture mobilises past and the laws of physics to craft a predictable deep future.

The fractured bedrock is ‘renormalised’ (Barad, 2012) by the Finnish disposal culture through the translation of risk into predictability. Following Barad’s notion of renormalisation, Hird (2012) writes that waste management in general produces facts about disposal sites through the process of bracketing out indeterminacy. The presence of fracture networks in the Finnish bedrock is used by the Finnish disposal culture to produce determinacy from indeterminacy. In their safety case, Posiva note “groundwater flow at Olkiluoto takes place mainly through a network of fractures and deformation zones” and how models of these zones and network provide “information about the migration paths and flows” (Posiva, 2012: 129, 20). By mapping and avoiding spaces of unwanted risky movements the GDF can be constructed in a space that supports rather than jeopardises the facility’s ability to isolate nuclear waste for the long-term. The presence of well-defined fracture networks in the granite bedrock in which Onkalo is excavated is, thus, seen to provide for the predictability of geological processes and the performance of Onkalo. Existing fractures, in the first instance as possible spaces of risk, were mapped and used during the siting process to “form a cage” around the potential disposal site. This cage enables the avoidance of fractures within the GDF and reduces the risk of leaks in and out of the GDF in the future, while the GDF itself will be contained within a reasonably integral geological block away from major factures. Trust in the stability of these bedrock blocks and the stability they provide is at heart of predictability and safety making in the Finnish case. Eero, a VTT Research Manager, mused “the block structure has survived previous glaciations, it is most likely to retain its integrity in the future as well [and] while uncertainties naturally remain, conditions inside the bedrock are more predictable than aboveground”. Rather than as spaces of risk Eero sees fractures and the block structure of the bedrock as sources of predictability – and in any case the underground as more predictable than the aboveground.

The renormalisation of fractures as spaces of predictability relies on the notion that deep, geological time is cyclical. It is this cyclicality that is seen as a promise of predictability and safety (Adam and Groves, 2007). Claims for the predictability of the deep future rest on assumptions that deep time and deep process of the past will be repeated in the future. Predictions of geological processes, Rabbe explained, are “based on a belief that what happened one million years ago, or during the last million years, will happen again”. However he went onto note how “that won’t necessarily be the case. There will always be uncertainties”. The assumed cyclicality of geological processes is utilised to tell stories of the safety and evolution of the GDF in the future. The assumption of the cyclicality of geological time and processes, the assumption that what has happened before will happen again in the same spaces as before, together with the linear time and process of radioactive decay are mobilised to make the case for the safety and predictability of the deep future and GD.

Finally, available geological conditions play an important role in the ways in which underground safety is constructed in Finland. Finland is geologically relatively homogeneous and the choice of geological environments suitable for GD is limited. Granite, Posiva notes, is the “only realistic choice of host rock” (Posiva, 2012: 35). A former Posiva Research Manager, Juhani Vira, has noted that Posiva “can’t influence the waste or the site [but] have to take them as they are” (Vira and Jalonen, 2014). Available geological conditions inform and shape the ways in which safety and safety claims are made through relational articulations. Ilkka contrasted the KBS-3 disposal concept being implemented in Finland to those of other countries. In Finland the aim of disposal, he argued, is to contain radionuclides inside the waste canister in the GDF, but “elsewhere, disposal concepts tend to allow the dispersal of radionuclides in clay, and hope that radionuclides travel slow enough not to jeopardise long-term safety. These concepts might be good, but they wouldn’t suit the Finnish system” due to the lack of geological alternatives. Because of the presence of fractures in the granite bedrock, dispersal of radionuclides would be riskier than in clay environments in which there are no obvious routes for movement. Where Matt underlined the slowness of movement in clay and van Luik argued that fractures in granite invoke uncertainty in the deep future, Ilkka turned these arguments on their heads. To underline the safety of the Finnish system, he posited clay formations as spaces of risk if or when waste has been allowed to disperse in clay. In clay, he argued, the possible movement of radionuclides is *more* unpredictable than it is in granite. In clay the movement of water and radionuclides takes place through diffusion, and movement can occur anywhere in the clay environment. Unlike in granites where movement is channelled to and by fractures to certain spaces, movement in is clay less predictable than in granites.

The different readings of fractures as spaces of risk and predictability highlight the negotiability and malleability of the bedrock (Sundqvist, 2002). The geological attributes of a site can be mobilised as arguments for or against safety and predictability into the deep future, and safety claims are made within the constraints of existing geological conditions. Geology, as the ‘ultimate barrier’ plays a key role in imaginations and makings of safety into the very distant future, yet GD, at its core, is an engineered concept. In the following section I will focus on how the design of the EBS reflects attempts to make safety in the very long-term, and secondly, how time is managed in the lab to predict the performance of the EBS over time.

5.3 Technology of stagnation

“Digging down into the Earth” Williams writes, “is also going back into the past” (Williams, 2008: 23). By moving underground, GD seeks to enrol the past to create, but also to make and protect the future. The making of safety draws on the past both in spatial and engineering sense. Familiar, historical materials, as I will explore further below, have been chosen to contain nuclear waste. Nonetheless, as we observed earlier, the one million years the GDF is assumed to contain nuclear waste surpasses present engineering ability. The timeframe of GD, William noted, is “an enormous time in engineering terms”. The one certainty about GD is the eventual loss of containment. Matt pointed out that the GDF “probably will fail. The thing is not going to be watertight forever. So it has to fail safely”. The relationship between safety and failure in GD is more nuanced than a simple dichotomy. Failure does not necessarily mean the loss of safety. Failure *can* occur in a safe way. Safe failure is a matter of time. Safety is no longer associated with *not* failing, but rather with failing in a timely way. If the GDF fails *before* enough time has passed since the emplacement of waste in the GDF, before enough radioactive decay has taken place, failure is risky. If the GDF fails *after* enough has passed, failure is no longer opposite to safety. In any case, safety does not mean the containment of nuclear waste forever. The IAEA has posited, “disposal facilities are not expected to provide complete containment and isolation of the waste forever; this is neither practicable nor demanded by the hazard of the waste, which declines with time” (IAEA, 2012: 4). The dual process of decay – the natural decrease of radioactivity in nuclear waste on one side, and the loss of the EBS’s material integrity on the other – means that while the GDF’s ability to contain nuclear waste unavoidably decreases with time, so does the need for the isolation and containment of waste. However, the incommensurability of EBS and radionuclide lifespans, as we have already seen, guarantees that the EBS will fail before radionuclides have reached the end of their lifetimes. Thus, the task for waste management organisations is to engineer containment for *long enough*, to extend the lifespan and material integrity of the EBS enough so that failure can occur safely. Matt elaborated that the idea of the safe failure of the GDF draws from nuclear reactor technology.

> A failsafe reactor is designed so that in the event of some accident, it takes itself to a safe state to be intervened with. […] In terms of design principles that leads you down a certain way of thinking. So, if it's going to fail safely, you tend to want a very simple design basis. (Professor of Nuclear Materials, interview)

Safety is associated with simplicity and the design of the GDF, on paper, is fairly simple, a point to which I will return shortly. The GDF as an engineered structure, however, is loaded with immense expectations. It has to maintain its integrity for longer than any other human made structure yet and operate for longer than human civilisation has existed. Also, the GDF design process diverges significantly from ordinary engineering practices. It pushes those practices beyond their conventions. Matt pointed out how normally engineered things are "product[s] of multiple failures"; they are designed, modelled and tested on different scales. They go through multiple iterations and closure scrutiny.

> So before you build the first product, you've got a very good idea that it's going to work and you've ironed a lot of the deficiencies. Sometimes, it doesn't work out that way. The Millennium Bridge is a good example of that. But the geological disposal facility won't be like that. The first one we build will probably be the only one we build. (Professor of Nuclear Materials, interview)

The GDF is not afforded, cannot be afforded, the same trial-and-error approach to its design as engineered things commonly are. With the GDF there is not a chance to smooth out technical hiccups and deficiencies with the next iteration. There will only be GDF 1.0. On the other hand, the design of the GDF is not what one might think of as an innovative novelty. Its design depends on concepts and materials that already exist. The GDF is designed in the image of nuclear reactors as it relies on the same design and safety principles. The safety of the GDF like that of nuclear reactors rests on a multi-barrier system (see Figure 1 in the Introduction). The KBS-3 concept Finland is implementing is composed of five barriers:

- Ceramic spent fuel elements
- Copper waste canister with a cast iron insert
- Bentonite (also used as cat litter) buffer surrounding the canister
- Bentonite backfill with which the disposal tunnels are filled
- Granite bedrock.

The basic principle of the multi-barrier system is to provide 'defence-in-depth' or safety in numbers. The aim of the multi-barrier system is to "confine the radionuclides so that the failure of one component does not jeopardize the safety of the containment system as a whole" (IAEA, 2003: 18). This way the "uncertainties affecting […] one barrier or safety function typically have only a small effect on overall performance" (OECD, 2009: 152). Thus, the failure of one barrier does not mean the failure of the GDF, and should not affect the safety provided by the whole multi-barrier system.

The materials for the engineered barriers of the multi-barrier system are chosen and tailored with the waste and the bedrock in mind, thus in Finland for instance the materials are selected to suit and complement the dominating geological conditions in the Fennoscandian shield and the characteristics of spent fuel. As we can see from the list above, the materials chosen to contain nuclear waste are rather mundane: ceramics, copper, iron and clay (bentonite). Samuli weighed the strengths of these materials. The spent fuel element, he pointed out "is practically porcelain", a similar material to an ordinary coffee cup.

> A coffee cup won't dissolve in water; the fuel element is that kind of a material. Then there's the iron insert offering mechanical protection and copper providing corrosion protection. […] Then we have the bentonite that is used in landfills to prevent toxins from reaching groundwater. We have much experience of it and it provides good

> insulation. And finally we have the bedrock as a sort of ultimate protection. (PhD student, interview)

The mundanity of EBS materials is so striking that some scientists have speculated whether more novel materials might be more efficient in invoking ‘public acceptance’ and confidence in GD. While GD is described as ‘state-of-the-art’ technology, the conservatism of its material design does not necessarily reflect this claim (McKinley, Kawamura and Tsuchi, 2000). Aila, a Posiva Project Manager, however noted that it is precisely the mundanity and the familiarity of the materials that provides confidence in the disposal concept.

> It’s a system that is based on well-known materials. I mean this is the *fundamental principle* that we’re working with clay, copper, iron. We’ve known these materials. They’ve been around many, many years. So, *we can predict them*. (Posiva Project Manager, interview, my emphasis)

The familiarity of materials enables the prediction of their behaviour over long timescales. This is the reason why they have been chosen. Aila further elaborated; “we don’t want to use any fancy-schmancy engineered things that we don’t understand for those kinds of timeframes”. Novelty means a shallow understanding and experience of the long-term behaviour of materials and by extension a reduced predictability of the GDF’s long-term functioning. So, instead of new innovative materials, Posiva look to familiar materials and conduct ‘analogue studies’ on them. One such analogous artefact that has attracted the attention of Posiva and the Swedish waste management organisation SKB is a bronze cannon that contains vast quantities of copper. The cannon lay on the Baltic seabed for centuries. Surrounded by clay and abrasive seawater, the cannon provides a good analogue for the copper canister that will be surrounded by clay and groundwater in the GDF for multiple millennia (Ialenti, 2015). Ialenti describes how Posiva experts study the cannon to predict whether and how copper canisters might corrode over the long-term in order to forecast the evolution of the GDF into the deep future. By studying analogues and relying on familiar materials, the design of the EBS seeks to prolong the ability of the barrier system to meet, even if not match, the longer now of the radioactive hazard of nuclear waste.

Thus the Finnish disposal culture mobilises the past in a range of ways to make the deep future safe. In the first instance, the cyclicality of geological processes, the assumption that the past will repeat itself in particular spaces, is used to argue for the predictability and safety of the deep future. Secondly, safety and predictability are made through the material historicity of the EBS, the drawing on materials and evidence of the past, and the simplicity of the EBS design. The reliance on geological and archaeological evidence in making safety claims, and GD's attempt to manipulate time in order to make safety render GD a technology of stagnation. As a technology of stagnation, GD abhors novelty. The design of the GDF draws on safety principles applied in the design of nuclear reactors. Most crucially, however, GD seeks to slow down time. The move to the underground and the historicity of the EBS are an effort directed at extending the present of the disposal facility. Moved away from the atmosphere, the facility is anticipated to be less prone to eroding and corroding forces. Constructed underground, the facility is expected to have a longer lifespan than it would aboveground. Unlike the aboveground, the underground is seen to offer stable and predictable disposal conditions in the deep future. The passage of time underground is slower, which is important for the EBS. Underground the evolution, and the inevitable degradation of the EBS, slows down. While the life of the EBS cannot be prolonged to match the expansive now of nuclear waste, stagnating the decay of the EBS is crucial for making safety. Stagnating time and by extension the decay of the EBS are a vital doing for engineering safety and safe failure in the deep future.

5.4 Crafting deep futures in the lab

In contrast to Finland, in the UK there is little certainty as to the exact material configuration of the EBS. The lack of a disposal site and uncertainty about the waste inventory (Chapter 4 and Chapter 6) ensures that the size, design and materiality of the GDF all remain unclear. Composing a "meaningful safety case" for a GDF under these conditions is very difficult (Bailey, 2015: 1634). This amount of uncertainty at the policy level caused some very tangible problems in the lab. David, a PhD researcher working on cement materials worried how the present uncertainty about the GDF's material configuration might affect his work in the future. This uncertainty, he explained,

> makes it more difficult to justify myself. Basically my justification is that I'm working on the generic disposal [concept], which has kind of structural concrete, but also cement used in filling the gaps between waste packages in one of the vaults So, if they change that or change the type of cement used, it would possibly make my work irrelevant. (David, interview)

The absence of clear policy raised also some practical problems in the lab with regards to experimental designs. Jodie, also a PhD researcher, explained that her project's

> main focus is to look at the evolving geochemistry [of the GDF], which is a challenge, because no one's committing to saying what materials we are going to use [in the GDF]. So I'm finding it very difficult at this stage to build a project or a programme to just study it right now, never mind trying to make leachates and pore waters that will represent evolved (leachate and porewater) solutions. (Jodie, interview)

Telling stories about the deep future without much guidance as to what that future might look like was a matter of concern for the PhD students, and it intertwined with more immediate short-term concerns about the students' ability to complete their projects, the futures of their work, and their futures as scientists.

Yet stories about the deep future were told constantly in the lab and the ability to tell these stories emerged through mundane material practices. For example, Jodie's project, that I followed closely in the lab, mapped the early decades of the GDF after its closure, in particular looking at the evolution of a cement that is envisioned to be used as the tunnel backfill material in the UK's GDF. Realising the anticipated deep future in the lab required careful, but quite straightforward, management of everyday tools, samples and practices from Jodie. Her project mapped a particular time, 50 years post-closure, in the evolution of the imagined GDF. The conditions in the GDF, at that point, are expected to be free both of oxygen and carbon dioxide (CO_2), while pH-levels and the temperature in the GDF are assumed to drop with time, as the heat generated by radioactive decay will slowly decrease. Creating and maintaining these conditions in an oxygen and CO_2 filled lab that had normal room temperature required careful design and management of the experimental setup. The easiest, and really the only, way for Jodie to do this was to transfer her experiments into a glove box (see Figure 11). The glove box, like the bedrock, works as a physical boundary of control in two directions. When radioactive materials are involved in an experiment, the glove box protects the researcher and the lab from radioactive samples contained inside the box. In Jodie's case the rationale of containment reverted. What the glove box contained was the outside world.

The box kept contaminants, oxygen and CO_2, on the outside and protected samples and the future crafted inside the box from these contaminants. The glove box, thus, played a key role in the creation and maintenance of the deep future in the present. Jodie managed the atmosphere in the glove box by pumping gas into the box to ensure that no oxygen or carbon dioxide would linger and venture into the box while she was working on her experiment. For the same reason, all Jodie's tools and sample materials had to travel into the glove box via a vacuum chamber attached to one end of the box, to ensure that no oxygen or CO_2 would make their way into the box with Jodie's things. The lab had an oxygen depleter to help researchers such as Jodie know when oxygen had been evacuated from

Figure 11. Glove box.

the vacuum chamber and it would be safe to open the chamber from the inside of the box to access whatever tools were needed for a given experiment. The depleter, however, did not work and Jodie had to rely on her past experience of creating the future in the box in the present. In practice this meant waiting and was an exercise in patience: "I have to wait 20 minutes for the chamber to be vacked. It doesn't really take that long, but better to be sure. So we have to wait" (field notes 16 April 2015). Equally important to managing the atmosphere in the glove box to craft a space for the deep future in the present was the management of the temperature in which experiments would be conducted, as well as the manipulation of sample size. In the first instance Jodie explained:

> My oven is set to 50 degrees because the GDF will be at 50 degrees 50 years post-closure. So, that's the justification. Other people use heat to speed up the rate of reactions. If you then do the same experiment at different temperature points, you can work out how things are changing. (field notes 16 April 2015)

Mapping the evolving geochemistry of the cement backfill in the GDF relied on simple material doings such as managing the temperature of the crafted oven GDF. Ovens, which the lab had in the multiple, were time machines with which different parts of the future could be mapped. Not only did they help to make deep futures in the present, they also enabled scientists to stuff very distant or very long timespans into their three-year projects. The manipulation of oven temperatures sped up material reactions, which enabled scientists to map distant and/or long stretches of the future in a short period of time. A further aspect of this management of time was the manipulation of sample size. Just like high temperatures, small sample size was a tool for speeding up time and bringing distant times to the present. Jodie smashed her cement samples, which she mixed herself in the lab, into fine powder to further speed up the evolution she wished to trace (see Figure 12). The tools and methods she used to create the deep future were mundane at best:

> Jodie folds a sheet of A4 into two from the middle and places one of the cement crayons inside the folded paper. She picks up a rubber mallet and begins to hit the cement with it. She breaks half of the cement piece into smaller bits, which she pours into a mortar. Some of the pieces she snaps into smaller ones with her fingers. She grinds the pieces and pours them onto the sieve, which she then offers to me. (field notes 16 April 2015)

If the design of the actual GDF relies on simple materials, the deep future in the lab, too, was made with simple materials and tools. Paper, pestles, mortars and sieves that Jodie used can be found in many homes. Where the making of the future in the lab relied on simplicity, simple ways of working were imposed on Jodie by the anticipated deep future and the need to map that future in a glove box.

> A technician walks in; “Are you making a mess again?” he jokes.
> “Yeah, but don’t worry! It’s all contained in [the glove box].”
> He walks closer to see what we are doing. I’m hammering away at the cement and the technician jokes that his life is at risk while the hammering takes place. “I’d better leave!” he says and waltzes away.
> “If only he knew, it takes out ten minutes just to get the mallet out of the box!”, Jodie jokes as we are left alone.
> […]

> The technician walks back again. In silence, he watches us work for a while. “Isn’t there really an easier way of doing this? Looking at you is like going back in time. Don’t you get any mechanical stuff?”
> “Yeah, but not in the glove box. In Geography they have sieving stands where you put your whole sample in at once and then come back in ten minutes. Job done.”
> “Hmm. It’s like going back in time”, he mutters and turns around to leave. (field notes 28 April 2015)

Making the deep future in the present, having to contain work in the glove box to avoid the present leaking into the future-in-the-making, set limitations to work, and determined what Jodie could do, know and how. The future in the glove box was made through banal and slow manual labour. Tools bigger than ordinary mallets and sieves did not fit through the vacuum chamber, while samples configured to the future could not be taken out of the box without the risk of contamination. The need to predict the deep future, thus, structured work in the present just as much as the making of the deep future depended on tools, data and techniques available in the present.

Figure 12. Cement preparation in the glove box.

Nonetheless, Jodie was constantly aware of the precariousness of the future she sought to create and preserve in the glove box. Keeping the present from collapsing into the future, preventing oxygen and CO_2 from leaking into the glove box and coming into contact with samples was vital for making and maintaining the deep future and the project's capacity to predict and make knowledge claims about the evolution of the GDF. Jodie was aware that the present might leak into the future despite her efforts to contain it. She explained how her sample "pots had been qualified with ultra-purified water. I weighed them before and after the water. All pots lost around, or less than, 1% of their weight, which is okay, but at the same time [...] if water can get out, CO_2 can get in [to the pots]" (field notes 16 April 2015). Gaps between sample pots and their lids, tears in the gloves of the box, presented spaces of risk to Jodie's created future and, by extension, to her ability to map and make predictions about that future. To better control the reliability of her results, Jodie included a blank sample for each of her cement samples in the experiment. The blank, that is cement-free, samples, she explained, were there to monitor and verify the chemistry of the simulated leachate in which her samples sat in their pots, and to reveal any potential CO_2 leaks into her experiment. The main role of the blank samples was to inform Jodie that nothing in the glove box was contaminating her samples over the timespan of the experiment. Additionally, if her blank samples turned out contaminated or to have something strange in them, they could help her identify the contaminant. This might in turn salvage the credibility of her experiment despite contamination/contaminated samples.

The manipulation of materials and management of experimental set-ups brought the deep future into existence in the present. The deep future is a matter of material doings that take place in glove boxes, sealed sample pots and ovens that make the deep future in the present, creating conditions for its predictability. However, making predictability is a creative and an uncertain project, as we saw. The present can leak into the crafted future, and the million-year timeframe of the safety assessment defies knowing. Jodie noted how she "can't predict what's going to happen", but rather, "give a good guestimation" of how the deep future might unfold.

In the following section, I will continue to focus on the material makings of the deep future in the lab. In what follows, I will explore how the deep future was imagined and made through invisible-to-the-eye atomic spaces and material interactions.

Deep spaces of containment

If the material manipulation of time through sample size, temperature and atmospheric conditions enabled Jodie and others to work with the future in the lab, manipulating sample size also opened up deep atomic spaces of containment for closer examination. Where the underground, depth and distance from the surface, are posited as providing safety in the very long-term, in the lab, as well, containment and safety were created and examined in subsurface spaces. Rather than the bedrock, the focus was on the deep spaces of potential EBS materials. Alex, whose project sought to identify an optimal glass-ceramic mix for the containment of plutonium residues[11], was interested in the hidden, invisible-to-the-eye, properties of her samples. Glass-ceramics, Alex explained, are explored as a potential wasteform for the containment of plutonium residues due to the dual containment capacity of glass-ceramic materials. "You have the glass phase which will incorporate the fission products or other stuff", she explained, "and then you've got your ceramic phase that will take [plutonium] […] It is a two-phase wasteform where you've got actinides in one and all the other stuff in another [phase]". Alex further noted that the dual characteristics made it easier to engineer containment.

> You're kind of taking the advantages of glass and ceramics. You take the higher loading capacity of ceramics, higher durability of ceramics, but you're also taking the ease of processing from the glass. By adding just a small bit of glass to the ceramic […] it's a lot easier to process than just straight ceramic. (Alex, interview)

What Alex was really interested in was the inner world of her glass-ceramic samples; what their structures were like, how they came to be what they were, and how her glass-ceramics interacted with waste. By exploring the atomic spaces of her samples, Alex could map where the "waste is preferentially going. Does the cerium go into the glass phase or titanium phase or zirconium? Or does it split equally across the board?". Alex used cerium as an analogue to

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[11] Plutonium residues are classified as high-level waste. They contain more plutonium in them than intermediate plutonium-contaminated waste, but not sufficiently to warrant the extraction of plutonium and uranium, and their recycling as fuel, economically viable.

plutonium in her experiments. She explained how “cerium is not the best analogue for plutonium. Cerium is used, because it has a very similar ionic radius to that of plutonium. Cerium and plutonium are similar in size, but cerium reduces more readily than plutonium does”. In a ‘real’ situation, then, plutonium might no behave as cerium did in her experiments. Yet, the logic of these analogue studies, Alex explained, was to enable “non-active[12] research [to] try and predict what the waste would do, rather than just looking at producing a special glass, but not actually knowing how the waste is going to work”. By tracing the movement and distribution of cerium in her samples, Alex hoped to be able to predict and identify how plutonium might distribute itself in glass-ceramics, and additionally, to identify an optimal glass-ceramic wasteform to contain plutonium into the very distant future.

Studying the microstructure of her samples could reveal the respective abilities of her sample materials for containing waste. Glass-ceramics, Alex explained, have “about a hundred per cent density with no porosity, which is why I’m interested in it”. Porosity in glass-ceramic, like fractures in the bedrock, can be interpreted as spaces of risk. The more porous the wasteform, the more uncertain its ability to contain waste materials is. Because of the absence of porosity, glass-ceramics are suitable for the containment of radionuclides, and plutonium in particular. Mark, a lab technician at UK university, explained that

> If you put plutonium as a single atom in a ceramic structure, you’re bonding it. It’s actually in the structure. If that ceramic doesn’t disintegrate too much, it’s the best way to keep that stuff in one place for thousands of years. In a glass, it’s slightly more likely to leach out. (UK Technician, interview)

The density of ceramics promises containment and ensures that extracting plutonium from a glass-ceramic wasteform is highly difficult and unlikely. Thus, the material Alex was studying could carry both security (non-proliferation) and safety (containment of radiological hazard) functions. “On a molecular scale”, Mark continued, containment is “quite easy”. It is these deep, microscopic spaces that researchers map in order to craft and make predictions of safety

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[12] Experiments that do not use radioactive materials.

into the deep future. Not only do they trace how waste materials split in wasteforms, like Alex did, but they also map the “atomic scale to predict how th[e various] interaction[s] could affect the engineering and the environment of a GDF over hundreds of thousands of years” (Diamond Light Source, 2015). These deep spaces of the EBS, then, entangle with time. They are spaces where imaginations of safety, containment and the very distant future are crafted and examined.

These deep spaces, however, are often overlooked in public representation of GD concepts and safety. Internationally, all disposal concepts rely on the kind multi-barrier system that we saw above, which aim to contain radionuclides for sufficiently deep into the future both in time and space (NDA, 2010). In descriptions and international comparisons of GD concepts, attention is guided to the materials and the redundancy of barriers. Visual representations, such as the NDA’s depiction of the UK’s envisioned EBSs for low and high heat generating wastes (see Figure 13), focus *on* rather than *in* the materials. Focus *on* the materials describes the material configuration of engineered safety, the different materials chosen for an EBS. It also visualises the isolation of nuclear waste inside the EBS and the bedrock. Depicting smooth materials surfaces in decontextualized environments, public representations, such as the one above,

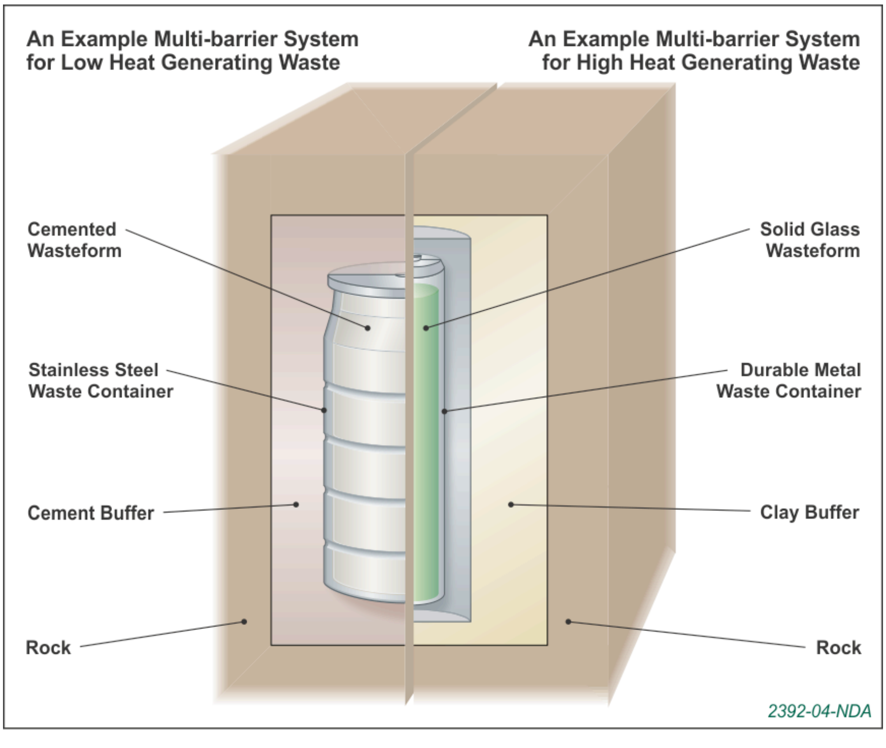

Figure 13. Multi-barrier system. Courtesy of NDA.

simplify containment. Together with the complexity of the EBS and the bedrock, what is invisibilised in such depictions is waste itself. Visual representations of the EBS craft dual containment in a sense. By displaying a decontextualized EBS they contain the uncertainty and contingency of containment, and by extension by invisibilising waste inside the depicted EBS, these representations remove the hazard and liveliness of waste, instead presenting them as tamed and ordered (Gregson, 2012). The above visualisation by the NDA, for instance, depicts how the two types of wastes are neatly contained within waste canisters that are held in place by buffer materials and surrounded by the bedrock. What is absent are, not just wastes but also, descriptions why the material configurations of these two EBSs are so different; why the system for low heat waste is composed of cement, stainless steal and another layer of cement, while the high heat waste system relies on glass, metal and clay. Such visualisations invisibilise where and how containment takes place. They do not elaborate on why certain carefully chosen materials have been delegated the roles they have within the EBS. The dual absence of descriptions of design and of waste blackbox containment that becomes represented as a matter of fact, instead of the intricate and precarious doing that it is.

In contrast to these public representations that focus on materials, in the lab the focus is very much *in* the materials. To assess the suitability of her samples for the containment of plutonium residues, Alex was interested in the microstructure and porosity of her samples, how different ingredients of her samples reacted during the sample preparation process and how they assembled into a glass-ceramic form. To map these qualities, she had to utilise different analytical techniques.

> SEM [scanning electron microscopy] shows the microstructure of my samples. It can reveal any porosity in them; whether I've got unreacted material in there, large crystallites, small crystallites. It basically zooms in on the micron scale for us to really see the structure in our phase assemblage; what it looks like. X-Ray Diffraction basically gives us our phase assemblage. Each crystalline phase has its own fingerprint peaks map, which we can match with

> the standard cards. Each peak is for a certain fingerprint of the phase kind of thing. I mainly use it for phase identification. (Alex, interview)

What matters less is the glass-ceramic material. What is of interest for Alex is the way in which glass-ceramic material, composed of a range of elements, assembles on the microscopic level. She explored the characteristic of six different glass-ceramic samples, which varied from each other in their composition only slightly, with the aim of identifying the most suitable composition for the containment of plutonium residues. As with the GDF, the containment within a glass-ceramic material is the effect of multiple elements coming together. The ability of glass-ceramic to contain waste emerges from the invisible-to-the-eye encounters and relatings of materials that together compose the glass-ceramic barrier.

Different techniques for examining the deep microscopic spaces of glass-ceramics to map its ability to contain plutonium residues governed the ways in which Alex prepared samples and managed sample size. Much of her lab work was guided by the invisible-to-the-eye atomic spaces and lab instruments' ability to map these spaces. The process from sample preparation to data analysis involved constant negotiations with materials, instruments and other researchers. From being assembled from powder samples, Alex's samples went through smashing, sieving, grinding and/or polishing depending on her analytical needs. These routine material practices served a dual purpose: they could be used to manipulate time, as I described above, but also to visibilise spaces of importance. To produce accurate data, instruments demanded careful sample preparation. The ability of the X-Ray Diffractometer (XRD) to produce accurate data for Alex, for instance, depended on the grain size of the sample: the finer the grain, the better and clearer the data. Sometimes, poor sample preparation opened to touch, although it remained invisible to the eye. Setting up an XRD run, Alex began to question her preparation work and consulted a fellow PhD student.

> Alex: "Do you think these powders are too coarse? They are 106 microns.
> Other: "How much?

> Alex: “106 microns. You can rub them between your fingers.”
> Other: “I’m sure it’ll be fine.”
> (Field notes 10 April 2015)

Alex’s haptic encounter with her sample proved out to be accurate. Although the feel of the sample justified Alex’s concerns, she initially trusted her sight over her touch. The data from the XRD came out “too noisy” and Alex had to re-run the XRD with double the initial time. The length of the run directly resonated with the XRD’s ability to visibilise the deep spaces of containment that Alex could not otherwise access. Yet, even when accurate, data produced by the XRD was open to interpretation and subjected to simplification. The XRD produced diffraction patterns of the materials it analysed. On a pattern, each phase present in the sample was represented by a unique ‘fingerprint’. Each fingerprint has its particular predetermined place and shape on the pattern, and researchers can identify their phases by comparing and matching them to the standard phases in a reference database provided by an XRD compatible analytical software. The database used by the Alex and others in the lab constituted of over 340,000 fingerprints against which researchers made sense of their samples. Experienced researchers, such as Matt, could “immdediately tell” if a fingerprint on a pattern was an impurity (field notes 11 February 2015), while more inexperienced researchers had to rely more heavily on the database. This left space for interpretation and negotiation. Differentiating between noise and peaks, actual phases and impurities, was not necessarily straightforward. Different methods were available for researchers to make up their minds. Alex reflected that some researchers relied on statistics and percentage offered by the software to help them tidy up their data identifying anything “five per cent above noise as a peak”. Instead of relying on statistics, Alex made her judgements “by eye” (field notes 20 May 2015). She mused that sometimes she had to be more “brutal” with her peaks, which allowed her to relegate them into noise easily and swiftly. At other times, cleaning her data could involve a great deal of compromising and weighing of options;

> The data is messy. Alex determines the fate of peaks on her pattern by how they relate to each other: if this one’s a peak, that one must be too. Then there is the shouldered peak that doesn’t coincide with

> the standard. Where Alex's peak has a shoulder, the software offers two peaks She decides it is a match since the correspondence between the standard and her sample isn't "too bad". (Field notes 20 May 2015)

This kind of discrepancy between samples and standards were dismissed in the data generation process. The parts of the glass-ceramic that did not fit the standards were neatly brushed aside by Alex as she made her samples fit idealised data offered by the database. The sample became translated into and treated as those idealised neat pieces of data and it lost the messiness of the powders and patterns with which Alex mostly engaged.

Cleaning and generating data was inherently a process of interpretation and creation. In the lab, scientific objects are both produced and transformed. Knorr Cetina writes how lab work requires that interpretations and selections are made: "any definition of what is or is not the case, any specification of a course of action, of a measurement device or a chemical composition is in principle a choice among alternative means and courses of action" (Knorr Cetina, 1983: 157). Data, and by extension safety claims, are made through selections. Diffraction patterns have interpretative flexibility (Pinch and Bijker, 2012). How Alex interpreted and cleaned her data was guided by the problem to which she was seeking an answer. As she was trying to identify the phases in her sample, she removed or ignored the peaks that did not fit the idealised phase types, while sometimes she dismissed the identifications suggested by the analytical programme she used.

> Alex explains that she has to decide what's a peak and what's not: "when you zoom in, this one's a peak, but when you look at the whole picture it's not. You got to take you time with this, because what you say is a peak the machine will then use to analyse the data. This, for instance, isn't a peak but noise, so I'll take it out". One of her peaks has a ledge and she assumes that there are two peaks, but they just haven't come off for some reason. Nonetheless, she decides that her data matches with the computer's suggestion of two

> separate peaks. […] "They aren't the best match, but they fit quite well". (field notes 20 May 2015)

Through a long process of manipulation and tweaking sample materials and messy diffraction patterns were translated into trimmed representations of her samples on a computer screen that were more informative to Alex than the materials she was working with. The deep spaces of materials were simplified to accommodate the making of safety into the deep future. The neat representations in the shape of diffraction patterns or SEM images could tell stories about the deep spaces of containment the sample itself was incapable of doing. These representations gained lives of their own and in ways outgrew the significance of samples as knowledge making devices (Latour and Woolgar, 1986 [1979]). Once created, they could exist without the original sample and became key in mapping the ability of wasteforms to contain nuclear waste, and the evolution of the EBS in the deep future.

5.5 Summary

The central argument laid out in this chapter was that *the deep future* and *safety* are made through intricate relational and situated doings. Safety is not an inherent quality of GD, but emergent of contingent doings and local negotiations. In this chapter I traced some of the ways in which safety, together with the deep future, are crafted. I explored how underground safety is made in relation to the aboveground that is constructed as an inherently more unpredictable space. Geological safety, then, is negotiated and negotiable. I explored how safety in the Finnish case has been made through reflecting the underground against the aboveground as well as the renormalisation of underground spaces of risk as spaces of predictability, and we observed how the ontopolitics of fractures in the bedrock depend on available geological conditions and choices.

Additionally, I traced how the deep future is made through separations, simplifications and the manipulation of time. In the first instance, time is manipulated through the move from the above to the underground. Underground, processes, events and the passage of time are slower. This slowness, the international nuclear waste community has argued, helps to prolong the longevity of containment. Eroding and corroding processes that inevitably affect the GDF will take longer, than they would on the surface, to damage the GDF's ability to contain waste. Because of the relatively slow passage of time, the underground is posited as a *safer than* space the aboveground. Constructed underground, the lifespan of the GDF, although still too short for radionuclide half-lives, but it is better matched with the lifespans of radionuclides than it would be aboveground. Digging into the underground can be seen as 'world reduction' (Jameson, 1975). What is reduced from the underground world in the first instance is the pace of time and the human. Disposal cultures envision safety through the separation of the human and the nonhuman, the aboveground and the underground. Where safety is delegated to the underground, the human is conceptualised both as a threat to safety as well as an object of protection. The human is seen as unpredictable, and the deep future made and imagined as a nonhuman space. As we saw, world reduction takes place in the lab as well. In the lab Alex cleaned and simplified her glass-ceramic elements to match idealised standards in an existing database. The identification of elements required the ignorance and brushing aside of inconvenient presences in her sample materials. The making of safety and safety claims relied in part on 'simplifying reality' and reducing the world to manageability. This is reflected also in the design of the GDF, which rests on simplicity and familiarity. The design of the multi-barrier system is based on mundane materials of which human society has much experience. The familiarity of materials and the simplicity of design are seen as fundamental safety factors.

In the following chapter I will explore same of the ways in which the deep future envisioned through and by GD has been contested within the UK and Finnish disposal cultures.

6 MAKING A MESS OF FINALITY?

In the previous two chapters I have considered both the making of the nuclear waste management problem and the making of safety into the deep future through situated doings and relatings. In this chapter the focus will be on the notion of the finality of GD, and how different ways of relating with it might affect the implementation of GD. As I noted in the first two chapters of this thesis GD is envisioned as an “end point” (EC, 2011) to nuclear waste management and a “permanent solution” (DECC, 2014a) to the nuclear waste problem. In Finland GD is referred to as *final* disposal (*loppusijoitus*), which seems to underline GD’s promise of an ending. The finality of disposal signals, on one hand, the envisioned difference between disposal and storage (DECC, 2014a), but it also decentres and invisibilises uncertainty. Final disposal, as a term, seems to simplify both the geological and the waste. It invisibilises spaces of geological risk and pacifies waste. ‘Final disposal’ proposes an end point in the lifecycle of nuclear waste. In doing so, it suggests the controllability of waste.

In this chapter then, I explore how the disposal cultures in the UK and Finland relate to notions of finality and the future. I will begin by exploring how in Finland Posiva has crafted the final disposal project into a ‘success’ story, and how this narrative relies on particular temporal imaginations of the future, which have become contested with the beginning of waste disposal in Onkalo drawing closer. Secondly, I will look at how the UK’s envisioned nuclear future may impose further challenges on implementing GD as a ‘permanent solution’ to the waste problem. In the last two sections of this chapter I will focus on the ontopolitics of waste and explore it through the technologies and notions of reprocessing and retrievability, and how these relate to, underline or undermine GD as a permanent solution to the nuclear waste problem. The argument here is that Finland’s more flexible approach to finality may at least partially help to explain the advances made by the Finnish GD project, while the more rigid approach reading of finality in the UK might present an obstacle to the implementation of GD.

6.1 Making a success story

Finland is among the handful of countries that have made notable progress towards the implementation of GD. At the moment it seems that Finland will be the first country to begin the disposal of nuclear waste, around 2025. The Finnish disposal culture has crafted a GD ‘success story’ that has been crafted by relating Finnish progress to a perceived stagnation of GD projects in other countries. The Finnish disposal culture also attributes this ‘success’ to a project timetable that is based on TVO’s waste management plan from the early 1980s. Ilkka, a retired Posiva Advisory, noted how

> In Finland in the early ‘80s, we quite smartly drew a long-term plan and strategy how [GD] will be taken care of, and defined checkpoints for evaluating whether and how to take the project forward. I do think that this was the smart and sensible way to go about it, and actually others should have done the same. (Posiva Advisor, interview)

The project timetable is seen not only as a source of success, but also as a source of exceptionalism. Above, Ilkka contrasts Finnish progress with the perceived inaction in other countries by proposing that the long-term plan drawn explains the progress the Finnish disposal project has made, while other countries, lacking such a plan, have faltered. Samuli, a PhD student, similarly weighed that the progress made by the Finnish GD project as “pretty telling of the Finnish mentality”. He viewed the Finnish approach to GD as fairly unique.

> We are kind of taking a different approach to the rest of the world. We want to dispose of the waste as soon as possible. So, we won’t leave the burden of hundred years of nuclear waste stored away somewhere for future generations, which is basically what other countries are doing. Their concept is to wait for technological advancement that enables the reuse of their nuclear waste. (Finnish PhD student, interview)

In Samuli’s reading, Finland is exceptional in that the country, unlike others, is actively implementing GD. As we saw in Chapter 4, in Finland nuclear waste management, including GD, was politically established as a prerequisite for nuclear operations. Although the 1978 Nuclear Waste Report noted how "no technically urgent need for final disposal [had] existed [and] the aims of waste research [were] far in the future" (Nuclear Waste Report, 1978: 1), in Finland the politically forged union between the nuclear present and the waste future forced the industry to act with some immediacy. Still, the biggest urgency for the industry was not the management of waste in the present, but the provision of a credible waste management plan for the future, as a means for securing nuclear operations in the present. Ilkka explained:

> TVO wouldn't have voluntarily started with such urgency, but it was made clear to them that their operational licence would not be renewed, if the disposal project wasn't set in motion. So, it was a bit of a carrot and a stick situation; they were made to act in the present. (Posiva Advisor, interview)

The Finnish approach to nuclear waste management could be conceptualised as anticipatory. Rather than addressing an urgent waste problem in the present, the Finnish disposal project was governed by the anticipation of future waste arisings, and having a waste management solution or solutions ready when they would be needed in the future.

TVO's plans and timetable for the implementation of GD drew on geological time. Radionuclide half-lives offered, and were used as, parameters for planning the Finnish nuclear waste future in the short-term.

> The timetable actually has a very pragmatic foundation. […] The basis for the timetable in the 1980s was the cooling down period of [spent] fuel. According to that the beginning of disposal could be take place in 2020. (Posiva Investigates, 2003: 2)

The original timetable for the implementation of GD mobilised radionuclide half-lives to justify a particular course of action. TVO worked backwards from the earliest possible disposal date to craft a structured project plan with clear milestones set between the anticipated beginning of disposal in 2020 and the beginning of the GD project in the 1980s. Site selection took place according to the initial plan in 2000 and the construction of the GDF similarly began in line with the original timetable in the 2010s. The presence of a clear structured timetable, which the Finnish GD project has stuck with, has been important in crafting a ‘success story’. That timetable has formed the backbone of the Finnish project. Rabbe from GTK explained

> The timetable was defined in ’83 and it is quite amazing that it has held up so well and seems to hold to the end. In the timetable the 2020s, that at the time felt very distant, were defined as the start of disposal and it seems that this will happen. (GTK researcher, interview)

The timetable, then, is assigned a central role in crafting continuity and successes of the Finnish project. After the 2001 Decision-in-Principle (DiP) approving Eurajoki as the GDF host community, the Minister of Trade and Industry Sinikka Mönkäre opinioned that the DiP represented a “logical continuation of all the work that has been done in line with the target timetable for final disposal that was drawn in 1983” (Posiva, 2001: 1). Similarly, in the immediate aftermath of the 2001 DiP Posiva CEO Veijo Ryhänen positioned the DiP as an “important milestone in the decades long preparation that aims for the beginning of practical implementation in 2020” (ibid.: 2). The initial project timetable was retrofitted as a definitive early stance on GD to bolster imaginations of commitment and continuity. These imaginations have been well rehearsed and were drawn upon again in 2015 when decisions on Posiva’s Construction Licence Application (CLA) for the actual GDF were imminent. Posiva reimagined the initial ‘target timetable’ as a ‘policy’ on nuclear waste management. The company posited that the “2001 Decision-in-Principle was a logical continuation of the policy that was agreed in 1983”, and further held that a positive decision on the CLA would be a logical continuation of the 2001 DiP (Posiva, 2015: 4).

In the Finnish narrative the disposal future is seen to flow directly from the past and the present. A linear trajectory for the GD project has been crafted with a certainty of progress that did not originally exist. In a 2015 parliamentary debate on Posiva’s CLA, MP Kristiina Salonen asserted that by ratifying the CLA the parliament “demonstrated great wisdom in deciding to follow a decision from 20 years ago” (PTK 62/2015: 6). Such re-imaginings of the project in terms of linear progress mobilise the past as a justification for decisions made in the present. Both in 2001 and 2015 decisions about the future were, in a sense, perceived as determined in and by the past, and thus already made. GD had become a megaproject with its own temporal logic and high political stakes (Lehtonen, Kojo and Litmanen, 2016). The Minister of Employment and Economic Affairs Olli Rehn saw the 2015 positive CLA decision flowing from the timetable set out in the early 1980s. He held

> [The] construction of Finnish nuclear safety has been patient. Current nuclear waste policies were drawn more than 30 years ago in the early ‘80s. Based on those plans, final disposal has been systematically planned for decades. (PTK 62/2015: 3)

The Finnish GD project is imagined in terms of commitment, continuity, and commitment to continuity. These notions tied to that of progress through decades have enabled the telling of stories of Finnish GD success. In 2000, Posiva Communications Manager, Osmo Kurki contemplated how “final disposal has been researched and prepared for 20 years and another 20 years of research and preparation are still ahead before the final disposal facility is operational” (Posiva, 2000a: 2). Drawing from work done in the past Kurki extrapolates a narrative of progress into the future all the way to the beginning of actual waste disposal. All this before Eurajoki had been ratified as the host community and the island of Olkiluoto as the disposal site. The notion of progress is tied to that of success, which in itself is portrayed as something that could be expected. That the Finnish project has progressed is not considered a surprise. In another newsletter from the same year Kurki noted how “in Finland different regulations and instructions are taken seriously and action is taken accordingly” (Posiva, 2000b: 2). In this reading, the progress of the Finnish GD project is not unsurprising, but is in fact also expected.

While progress of the GD project has, thus, been taken almost as a matter of fact, Finnish progress is mirrored to advances made elsewhere. Differences in levels of progress are mobilised to further bolster a narrative of Finnish success.

In a 2003 newsletter, Posiva noted how the company “has become a pioneer. Finnish nuclear waste management belongs to the vanguard of its field. It is quite satisfying to think one is part of a success story” (Posiva, 2003: 2). Additionally, in a 2010 newsletter, Posiva visualises GD as Finland’s home domain by depicting the implementation of GD as a sauna (Figure 14). The image conflates the exceptional (GD) and the international with the domestic, everyday Finnish experience (sauna). Picturing the Finn at ease next to stove, literally, adding more steam, while others sit sweating uncomfortably, suggests that GD, really, is Finland’s domain – Finland is leading the pack. It is in control and knows what it is doing, while others appear to be struggling. The picture is indicative also of the relational construction of Finnish success. There is nothing exceptional about a Finn in a sauna. Rather, like the progress of the GD project, it is what is expected. Exceptionalism and success only emerges in relation to the others. It is the relative comfort with which the Finn occupies the space that is exceptional, not the fact that he is there. At the same time what is exceptional is also normalised. The depiction of the exceptional (GD) through the mundane (sauna), aims to convey the manageability of the exceptional. In a sauna, a Finn is in control, in a sauna a Finn knows how to behave, what to do and, ultimately, where the situation will lead and how it will come to its conclusion. Part of this narrative of a GD success story is Finland’s perceived

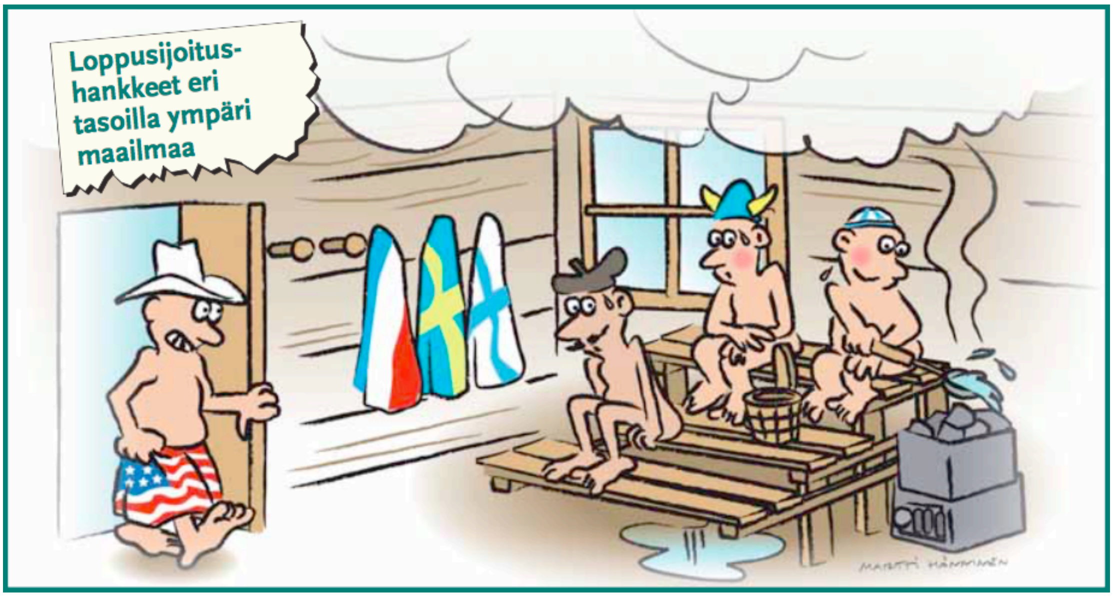

Figure 14. ‘Final disposal projects around the world on different levels’. Courtesy of Posiva Oy.

transformation from an apprentice to a pioneer. A Councillor at the Finnish Ministry of Employment and Economic Affairs (MEE) reflected how in the 1970s

and 1980s Finns attended international nuclear waste management meetings to "learn from others. There were the big leading countries […] we wanted to do […] what they were doing. As the years have passed we have progressed and little has happened elsewhere" (MEE Councillor, interview). Again, Finnish 'success' emerges in relation to stagnation elsewhere.

Up until the construction of Onkalo, the Finnish disposal culture expected it could and would take advantage of existing knowledge and technologies instead of being the one to produce them. Posiva's former CEO Timo Äikäs (2016) has joked that the only thing in which the Finnish disposal project has failed is that it has moved ahead of those projects from which it was meant to learn. Another former CEO of Posiva, Eero Patrakka noted in 2009 that the "aim was never to be the first in the world, but many other countries haven't had the courage to make political decisions about final disposal" (Posiva, 2009b: 49). Ilkka accounted that an "important lesson is that all those countries that tried to rush decision-making have had to return to the start line" while they should have, in his view, formulated a long-term plan like Finland did. In a 2015 Posiva newsletter article Juhani Vira mused how "one has to acknowledge that there is no philosopher's stone behind Finnish progress. Finland has systematically progressed step-by-step for over thirty years now" (Posiva, 2015: 4). The Finnish success story is crafted in relation to other countries and attributed to project planning and commitment to that planning, and the implementation of GD as a long-term project that cannot be rushed.

A long-term plan for a short-term future

In 2010 a Helsinki-based think tank Demos in its *Mission for Finland* report pointed to Finnish engineering mentality as a root cause for the success of the GD project.

> [In Finland] problems are rarely political, let alone moral. […] Finland is a country where engineering skill provides the answer even to the

> disposal of nuclear waste. In other countries this would be an ethical problem, here it is a practical one. (Demos, 2010: 82)

This engineering mentality and the related pragmatism are considered to be at the root of Finnish progress by others as well. A UK nuclear waste consultant noted that in comparison to the UK “Finland has a much more pragmatic population […] there’s definitely a bit of truth about the pragmatism”. Ilkka, similarly noted,

> Although it might sound quite naïve, cold pragmatism could be an important point here. I’ve read foreign comments and they mention that we have been quite pragmatic here. It can be either good or bad. I think it includes good things, but there’s also the risk that some difficult questions are ignored or aren’t debated properly. (Posiva Advisor, interview)

Where pragmatism in the form of timetabling and emphasis on getting things done have aided the progress of the GD project, the sensibility of the timetable and engineering emphasis of the project have become questioned as the beginning of actual disposal operations draws nearer. The timetable, broadly perceived as a vessel for progress by the Finnish disposal culture, has been contested by some Finnish scientists. There is a concern that the project timetable drawn up in the early 1980s has acquired a life of its own and transformed from a means to an end to the end itself. Eero from VTT noted that there has been a clear shift in the focus of the GD project since Posiva was granted the construction licence for the GDF in 2015. This shift in focus, he held, is observable in the workload of different VTT research groups that do consultancy work for Posiva. He noted that

> There has been some wrestling over resources in Posiva. What it means is that research into long-term safety, what our group for instance does, has been in trouble. In contrast, those in VTT involved in construction and planning research are almost drowning under their workload. (VTT Principal Researcher, interview)

From Eero’s perspective, “Posiva have practically hung themselves in the original timetable” and are pushing ahead with perhaps unnecessary urgency. He feared that the engineering mentality commented by Demos is taking over the Finnish GD project, as construction work rather than safety research increasingly, from is perspective, govern the GD project.

> What is worrying is that there are funds for construction and taking the project forward, but then [safety] research is beginning to suffer. […] The project is flashy. It’s big. It has to be taken care of. And then long-term safety, well, it’s not as flashy. Still if long-term safety is found to be inadequate, construction will cease there and then. (VTT Principal Researcher, interview).

A Finnish Geology Professor, Tapio, mused that the changing role of geosciences within Posiva’s project is potentially reflected in academia.

> Following funding cuts, the role left for geology [at the university] is a sort of support science for civil engineering to make sure that engineers, who know nothing about geology, will not completely mess things up. At the same time the research focus of the disposal project has changed, as the project has progressed to geological implementation. It’s more about canister placement and such like. In that sense geological research has been sidelined. (Professor of Geology, interview)

The concern here is ‘over the future of the future’ (Michael, 2017b). Both Eero and Tapio worried about the short-termism of GD future imaginations. The imagination of the future of GD through the *implementation of a project*, rather than through the deep future is embodied in funding decisions and prioritisation of activities. These decisions prioritising the short-term future are seen as risky. On one side, there is the risk of the degradation of appropriate geological expertise, as funding is being cut from geological sciences and resources are directed elsewhere. On the other, there is the concern that focus of construction rather than long-term safety renders the future that GD tries to create more uncertain and unpredictable than necessary, as resources are shifted away from scientific research and knowledge production to GDF construction. What such short-termism, the imagination of the future through the technoscientific timeframe of the *project* rather than the geoscientifc timeframe of *GD*, does is to overlook relations involving timeframes beyond human lifespan and history (Hird, 2009). Technoscientific and geoscientific timeframes are critically different. Humans are at the centre of the technoscientific timeframe that is “concerned with knowledge-building through relations between humans and nonhumans in historical, political, economic, and social context” (Hird, 2013a: 109). Technoscience, Hird writes, “brings to the fore current practices and imagined futures in which humans make up the world through the manipulation and management of nonhuman entities” (ibid.). In contrast, geological time begins with the ‘liveliness of inorganic and organic processes” rather than the human (ibid.). Geosciences recognise the ““radical asymmetry” of relations between humans and the vast expanse of nonhuman entities” (ibid.: 110). While geosciences traditionally explore the billions of years of Earth history, where the inorganic precedes the organic, in the deep future the human will make space for the nonhuman, and the organic to the inorganic. In either case, for geosciences the starting point is the geological, time and space without the human.

Making safety and safe disposal futures demand a geoscientific timeframe in which the human is decentred. They demand research that extends beyond the immediate human concerns, making space for nonhuman entities and times. The concern raised by some scientists in Finland is that the prioritisation of the immediate technoscientific future over the more distant future jeopardises the attempts to make safety into the deep future. Elina, who researches the effect microbes and microbial corrosion might have on long-term safety, noted

> We’ve only started research into microbial corrosion and we don’t even know yet what the opportunities are. New microbes are discovered all the time, and we don’t know what effects they might have. […] This research should have begun much earlier […] and there are indicators that microbes might be significant. (VTT Researcher, interview)

Matti, also at VTT, worried that there will not be enough time for research, if Posiva sticks with the original project timetable.

> Posiva's timetable is too strict. This corrosion business especially needs to be thoroughly investigated. We woke up to it too late. […] If it was up to me, I would call a five year time-out. Let's research this properly, and let's not build any disposal facilities before everything is clear. I'm not saying there is a problem [with corrosion], but it hasn't been out ruled yet. (VTT Researcher, interview)

Although GD itself remains uncontested and the future is envisioned through GD, the means and paths through which safe futures are made through GD are contested. The above examples indicate that the future "is not simply a neutral temporal space into which objective expectations can be projected" (Brown and Michael, 2003: 4). Rather the future of GD is contested even among those who are actively working towards its realisation. In the previous chapter, we similarly saw how the fundamental safety provision of GD can be imagined through different aspects of the GDF. Where Aila from Posiva underlined the material familiarity and predictability of the EBS as the 'fundamental principle' ensuring the long-term safety of GD, Rabbe from GTK assigned the same fundamental role to the block structure of the Finnish bedrock. Both safety and the future of the GD project, then, are negotiable. They are made through local doings that can be questioned and contested. Where safety is not an inherent property of the GDF, as the different interpretations of the GDF's safety provision illuminate, the future of GD does not automatically flow from the timetable, as suggested by Posiva and Finnish policymakers. Rather, the future made through GD emerges from situated doings and negotiations.

By extension, it is necessary to pay attention to the multiple temporalities at play in the implementation of GD in the makings of success. The 'worries over the future of the future' expressed by some Finnish scientists cannot solely be conceptualised through the perceived 'negligence' of geological timeframes. Concern over the future also focuses on shorter-term technoscientific futures of knowledge, skills and capacity maintenance. Eero, for instance, noted that the Finnish disposal culture is facing a major challenge and potential restructuring as Posiva's (external) research needs diminish with the beginning of disposal, and the company is expected to commission less research. The maintenance of skills, knowledge and jobs is a short-term concern for the Finnish disposal culture. Eero noted that Posiva funds and commissions approximately 90 per cent of the research done in Finland, thus the advancement of the project will have major repercussion for knowledge and skills maintenance. Posiva, Eero weighed, is

> morphing into a constructing organisation that will still commission research, but when the GDF has been built, Posiva will be a disposal organisation. With that the volume of research needed will decrease. If the research commissioned by Posiva gets halved, for instance, jobs in our research groups will disappear. This is something MEE should address and establish a working group or something to figure out how we'll deal with this. (VTT Principal Researcher, interview)

Thus while the progress of the GD project and the beginning of disposal is the aim of the Finnish disposal culture, that same progress is potentially seen to jeopardise the future capacity of the Finnish disposal culture to tackle GD related matters, as Posiva's immediate research needs decrease and as funds have been cut from academic geological training and research.

Definitions of 'success' depend on the ways in which distance to the future (Michael, 2000) is envisioned. Posiva, currently, appears to define the future as being close: the future is imagined as the beginning of disposal. Such short-term view of the future, together with the enrolment of the past decades of research and the relative stagnation of GD projects in other countries enable the Finnish disposal culture to craft a success story out of the progress the GD project has made so far. Eero, while also subscribing to the narrative of success, noted, "the beginning of disposal […] is only the beginning of the actual work. Everything until now has only been preparation". His reading of the situation locates the future further in time.

The making of a success story, like the making of safety relies on separations. Where the making of safety relies on the separation of the human and the nonhuman, the underground and the aboveground, and emphasises the nonhuman, imaginations of Finnish GD success underline human achievements. While the ‘actual success’ of GD is unverifiable because of the immense timescale of GD, the making of success stories relies on shorter-term visions of technoscientific futures that are manageable on a human scale. However, speaking of successes measurable on the human scale does not necessarily translate to the desirable functioning of the GDF in the very long-term. The rush to complete the already articulated success story, some of the scientist in Finland fear, might harm the safe deep future imagined through GD.

6.2 Delaying the disposal future

Looking back at the UK’s GD past, Arthur, a RWM Research Manager, reflected

> I can remember the times when it looked like there was going to be an underground rock laboratory up in Cumbria, and it was almost assumed that that would all happen and then in 1997 the government decided that wasn’t going to go ahead. Since then it has almost taken on a stature of nuclear fusion. That it’s always going to be 40 years away.[13] (RWM Research Manager, interview)

In contrast to Finland where the disposal future seems near and the disposal project is described in terms of continuity, the UK’s project has been characterised more by stop and starts – and what continuity there is seems to be the slipping of GD implementation further into the future. The lack of a disposal site puts the UK in a difficult position, as little progress towards implementation and GDF design can be made without a site. The 2014 *Implementing Geological Disposal* White Paper situated the beginning of GDF construction to the 2030s with disposal beginning about a decade later. While this timetable is dictated by the assumed length of the siting and community

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[13] The popular joke in nuclear circles is that fusion is always (at least) 30 years away. John Holdren, the director of the federal Office of Science and Technology under the Obama administration, noted, “it's actually worse than that. I started working on fusion in 1966 […] at that time people thought we'd have fusion by 1980. It was only 14 years away. By 1980 it was 20 years away. By 2000 it was 35 years away” (in Guterl, 2017).

engagement processes, the UK has, drawing on geological time, in the past also knowingly pushed GD deeper into the future.

The 1976 Flowers Report was followed by a flurry of siting attempts in the 1980s, none of which made any progress towards the implementation of GD. With each setback, the focus of the GD project shifted. John, a UK nuclear waste consultant reflected how the UK has "been chopping and changing" its approach to GD.

> For me, always, our work on geological disposal in the UK has been affected by short timescales. […] We started off with high-level waste in 1976. [We] focused on high-level waste for five years, and then jumped into intermediate level waste. Jumped from the surface back down underground and so on, so it's been affected by those political decisions. (UK nuclear waste consultant, interview)

As these changes in focus between different wastes and spaces did not yield the desired end product, the UK Government announced in 1981 that HLW would be "stored for at least 50 years until the rate of heat-generation has been substantially reduced" (cf. No2NuclearPower, 2012). Geological time, the necessity to store HLW in any case, was mobilised to justify a moratorium on the search for a disposal site. In a 1993 UK House of Commons debate MP Alan W. Williams questioned the Secretary of State for the Environment, Tim Yeo on "the earliest date he expects that a waste repository for heat-generating nuclear waste will be operational in the United Kingdom; and which sites have been considered for such a repository". In his response to the query, Yeo reiterated the earlier government statement:

> High-level radioactive waste is treated and stored at the surface for a period of at least 50 years, which will allow heat generated by the decay of radioactivity to reduce. *Decisions about the subsequent management of the waste will be taken in due course*. (HC Deb, 1993, vol. 234, cc. 13W, my emphasis)

The UK Government effectively postponed nuclear waste decision-making deeper into the future as this could be easily justified by reference to the characteristics of UK nuclear waste. Thus, the ways in which the UK and Finnish disposal cultures have related to the geological timeframe of radionuclides to prepare for nuclear waste futures are notably contrasting, as is the subsequent progress and focus of the projects.

Where in Finland half-lives were used as the foundation or temporal structure for the implementation process, in the UK half-lives were used to justify inaction in the present in the long-term management of nuclear waste. Perhaps reflecting the distantiated disposal future, the UK GD project with its many siting attempts has suffered from short-termism. John, a nuclear waste consultant, argued that the lack of long-term commitment to GD is reflected in the thinking about disposal futures in the UK.

> When the 2008 White Paper came out, everyone said ‘okay, yeah, we’ll be finding sites in a year or two’. It’s like what kind of knowledge has anyone got of the previous successful and partially successful programmes? I mean Sweden had a terrible start to finding its site, but they had a long-term approach and they kept to that long-term approach. […] We fundamentally don’t gather this-this long-term aspect, I think. (UK nuclear waste consultant, interview)

The UK’s commitment to GD has been characterised by a desire for quick solutions. As we saw above with each setback the UK’s approach to disposal has changed until the decision was made to momentarily abandon attempts to implement politically toxic and controversial disposal solutions. Ilkka similarly, weighing Finnish ‘success’ in a comparative context noted how “in the UK, Germany, even Sweden and the USA, all those countries that tried to take shortcuts to implementation have [struggled a little]”. Attempts to rush the implementation of GD have, thus, marked disposal projects elsewhere too. In the UK the discrepancy between political, geological or just GD project timescales has been difficult to reconcile. Since waste imposes “no short term threat to safety” (DTI, 2002: 10), the UK’s GD project has been dominated by electoral cycles. The postponement of decisions on GD and the subjection of the project to electoral logics and parliamentary politics have meant that the political and policy context for the implementation of GD has altered significantly over the years. Since the inception of the UK's GD project, the country's nuclear policy has shifted from an ambitious nuclear new build programme to no nuclear and back to new build ambitions, while the focus of the GD project itself has oscillated between waste classes, the aboveground and the underground. As we saw in Chapter 4, the nuclear ambitions of the 1970s motivated the Flowers Report. More recently when CoRWM was appointed in 2003 to review and recommend options for the long-term management of the "nuclear waste problem" (CoRWM, 2006: 14) nuclear power was considered an "unattractive option" because of its economics and "important issues of nuclear waste [waiting] to be resolved" (DTI, 2003: 12). Yet by the time CoRWM had reached its recommendations in 2006 after extensive public, stakeholder and expert engagement, the Government was backing nuclear again, believing nuclear "has a role to play in the UK not only in reducing emissions but also to maintain the diversity of our electricity generation mix" (DTI, 2006: 8). The GD project then has existed in instability with regards to the surrounding politics and also the scale and complexity of the waste inventory, as waste from nuclear new build will expand the inventory. By extension uncertainty exists about the timespan over which the future GDF might stay operational and open – this is governed by the amount of waste that might need to be disposed of in the facility. Moreover, Colin from CoRWM noted that the most ambitious new build scenarios are at odds with the UK's current waste management policy.

> Nuclear is back in government in a big way. And if you look at some of what they talk about; one scenario, you'll never actually get there if you try it, because it's so ambitious, but it's 75GW of nuclear electricity by 2050, which almost certainly means a return to a closed fuel cycle. (CoRWM member, interview).

Although Colin considers this scenario as utopian, a return to a closed fuel cycle would mean a return to reprocessing that under the current nuclear policy ceases in 2018. Nuclear new build would also, as was briefly mentioned above, contribute to the creation of a more complex waste inventory. As the number and design of potential new build reactors remains uncertain, waste from new build has not (yet) been included in the UK’s nuclear waste inventory. As long as the new build situation remains uncertain, the waste inventory and by extension the future of the UK’s GD project remains uncertain. Moreover, CoRWM has argued, “communities are unlikely to express a willingness to participate in a siting process unless they have a clear understanding of the waste inventory they may be asked to accept” (CoRWM, 2006: 145). In CoRWM’s view, then, as long as the waste inventory remains open, the progress of the UK’s GD project will be precarious. Colin, furthermore, noted that potential volunteer communities might define waste differently from the official stance. During the previous siting process in Cumbria local communities, he noted, “were very clear that they would not see spent fuel as a waste”. He mused:

> [the UK] may well get a community that says ‘no spent fuel’. […] You may well find a community that volunteers for the legacy or large chunks of the legacy, but not new build. And then what do you do with the new build? You have to look for a second GDF. (CoRWM member, interview).

Nuclear new build complicates GD future making in the UK. Communities that have become used to benefitting from reprocessing activities through jobs may well contest the re-classification of spent fuel as waste (rather than an asset) or object to the disposal of spent fuel due to nuclear weapons proliferation concerns. While communities might contest waste classifications or refuse to host an ‘open inventory’, new build and the inclusion of new build waste in the inventory stretch the period over which the GDF will have to remain operational. Colin explained,

> If you just confine yourself to the legacy, you know what it is. The inventory is defined, and the timescale what the waste will arrive in the GDF is defined, and then at the end of that, which admittedly is a hundred years or something, you lock the door and you walk away, and the GDF just sits there. New build spent fuel, if you manage that as a waste, it’s much more open-ended. (CoRWM member, interview).

John similarly noted that the UK has “dumped everything together into one project, rather than splitting it up into separate projects, which may be an issue in that [it is] less likely to achieve one single GDF”. The conflation of new build and already ‘existing and unavoidable wastes’ (CoRWM, 2006) injects uncertainty to the UK’s disposal project. New build waste might extend the period over which the GDF needs to operate, and it would definitely extend the UK’s nuclear waste inventory increasing the amount, complexity and characteristics of the waste packages that need disposal.

The relationship between nuclear new build and GD is contested. Matt reflected that GD is a necessary *justificatio*n for nuclear new build. He held that a credible nuclear waste management and disposal solutions as part of the UK’s “nuclear fuel cycle [are] really important, because otherwise you won’t have a mandate for nuclear energy production. [...] It’s important that we maintain a credible strategy, if we go for new nuclear build”. In line with his reading of the situation, and in contrast to the concerns about the conflation of new build and already existing wastes voiced by CoRWM and other actors, the UK Government in a 2007 consultation document *The Future of Nuclear Power* the UK Government posited that it “is technically possible and would be desirable to dispose of both new and legacy waste in the same repository facilities” (DTI, 2007: 122). In a 2009 document on the arrangements for the management and disposal of waste from nuclear new build, the Government further held that it was “satisfied that effective arrangements will exist to manage and dispose of the waste that will be produced by new nuclear power stations in the UK” (DECC, 2009: 2). Yet another national policy draft that offered the same conclusion of the future GDF’s ability and capacity to house both legacy and new build waste, sparked four CoRWM members to address a public letter to Ed Miliband, the Secretary of State for Energy and Climate Change at the time. In the letter the CoRWM members contended, “it is unknowable whether or not effective arrangements will exist” (Blowers et al., 2009: 1). Where the Government expressed confidence that the GDF will be operational when needed, the CoRWM members viewed the future availability of disposal solutions as uncertain, since no site or a willing host community had been chosen at the time. They also reiterated that CoRWM’s position on and recommendations of GD as the best available long-term waste management method applied only to ‘legacy’ waste, not waste from new build. The authors of the letter quoted the 2008 *Nuclear Energy* White Paper that stated ”before development consents for new nuclear power stations are granted, the government will need to be satisfied that effective arrangements exist or will exist to manage and dispose of the waste they will produce” and argued that the existence of effective disposal arrangements “is a matter of judgement not of ineluctable fact” (ibid.). In the letter Blowers et al. argued that CoRWM had not identified an existing solution for the long-term management of nuclear waste, but a process through which such a solution could be reached. They further underlined that since the siting process depended on the willingness of a community to host a GDF, “neither the scientific nor the social requirements have yet been met and consequently, in our judgement, it is not possible to conclude that effective arrangements ‘exist or will exist’” in the foreseeable future (ibid.). The UK Government has nonetheless stuck to its position and in 2014 DECC had relegated GD from a ‘prerequisite’ for new build, as argued by the Flowers Report, into a technology that “will […] support the development of new, low-carbon, nuclear electricity generation” (DECC, 2014b). This prioritisation of shorter-term nuclear policies with more immediate potential benefits and the Government’s headstrong commitment to nuclear new build might jeopardise the longer-term nuclear future envisioned through GD.

As was mentioned, Blowers and colleagues in their letter to Miliband noted that the policy recommendations made by CoRWM applied to existing and unavoidable wastes only. When CoRWM began its deliberations in 2003 its remit included “the materials that currently exist as waste or could arise over the next century or so as a result of decommissioning of existing nuclear facilities, both in terms of volume and radioactivity” (CoRWM, 2006: 19). By the time the Committee finished its deliberative process the Government’s nuclear ambitions had rekindled and in its 2006 Recommendations Report CoRWM wrote

> The main concern in the present context is that the proposals might be seized upon as providing a green light for new build. That is far from the case. New build wastes would extend the timescales for

> implementation, possibly for very long, but essentially unknowable, future periods. (ibid.: 13).

CoRWM thus saw that new build waste would introduce unwelcome uncertainty to the GD project. Moreover, the Committee was firm in its stance that its recommendations should not be read as justification for new build. This was partly because of the uncertain futures introduced by new build waste, but also because "the political and ethical issues raised by the creation of more wastes are quite different from those relating to committed – and, therefore, unavoidable – wastes" (ibid.). CoRWM argued that if a new build programme would be introduced, it would require a "separate process to test and validate proposals for the management of the wastes arising" (ibid.). Yet, in its shorter-term nuclear new build ambitions the UK Government has appropriated CoRWM's recommendations to support the new build project and overlooked CoRWM's objections.

From the beginning, the UK's nuclear future making has suffered from short-termism. Reactors have and continue to enjoy precedence over waste management in UK nuclear imaginations and policy making (Chapter 4). In simple terms this has left the UK's GD project open to contention. In the first instance, the rushed siting attempts of the 1980s were met with public opposition, the experiences and memories of which have made later GD implementation attempts more difficult. On one side, local communities draw on those past attempts and experiences of the nuclear industry (Wynne, 1996; Bickerstaff, 2012) to make sense of contemporary encounters with the GD project and the implementing bodies. On the other side, where Finland, for instance, has been able to harness the GD past as a positive resource in crafting and projecting a narrative of success into the future, in the UK this discursive tactic is unavailable. Rather, the GD past is considered a place best not to be revisited.

In a public meeting at the British Academy between RWM and the International Review Panel, compiled by the British Geological Society to assess RWM's geological criteria for its National Geological Screening, a member of the audience asked how the new siting process would differ from the previous that halted in 2013. He saw that the past process suffered from lack of transparency and opennes in terms of the management and public access to relevant geological data. The Chief Scientific Advisor of RWM responded; “I think it’s probably not worth going back into the detail of the past history, but […] I just want to reinforce […] that the whole emphasis of this new process is to be open and transparent”. While the Chief Scientific Advisor sought to guide attention away from the past of the project in order to focus on a ‘better’ future, beliefs about the past as a space of controversy may shape visions of the GD future. The audience member who asked the question, for instance, elaborated at length how the handling of data during the previous siting process eroded local trust in the fairness and openness of the implementation process and the implementing body.

Wendell Bell and James Mau note, “beliefs about […] history limit the range of alternative images of the future and make it more probable that a particular one, rather than others, will be dominant” (Bell and Mau, 1971: 20). This is not to say that the future is determined by the past. Rather, just like actions in the past set futures in motion (Adam, 2008b), past experiences inform visions and expectations of the future. Where “the future [can be] mobilised in real time to marshal resources, coordinate activities and manage uncertainties” (Brown and Michael, 2003: 2), the UK’s current nuclear future making with its new build ambitions seems to introduce, rather than manage, uncertainties pertaining to GD. This introduction of uncertainty might delay the arrival of the disposal future that is “created in the present through contested claims and counterclaims over its potential” (Brown, Rappert and Webster, 2000: 5) as a long-term solution to the management of nuclear wastes. The uncertainty introduced by current nuclear policies, the imagination of the GD future as empty and untainted by the past and present (Adam and Groves, 2007) together with the prioritisation of the present over the past and the future; nuclear new build over disposal; and the present siting process over previous experiencess, may undermine the future the GD project seeks to realise.

6.3 Atomic optimism narrowing down futures

A sort of optimism about nuclear things and materials (e.g. that a disposal solution will be found for new build waste) has and continues to characterise the UK's approach to the management of nuclear waste and materials. Plutonium is a good example of this. It is the embodiment of the dual promise of nuclear. It "was once thought to be the most valuable substance in the world. 10 kg would make a nuclear bomb, or generate 100 million kilowatt hours of electricity" (Brown, 2013). Plutonium is a highly toxic human made metal, a "by-product" (POST, 2016) of irradiating uranium fuel in a nuclear reactor. Due to its toxicity, plutonium is a safety risk. While outside the body it is fairly harmless, inhaled it increases cancer risk. It can, under certain conditions, self-sustain a chain reaction. This needs to be accounted for in its storage arrangements, and it makes plutonium unsuitable for routine waste treatment methods such as vitrification used for high-level waste. It also means that plutonium needs to be stored in small quantities in air-conditioned facilities to prevent it form reaching criticality and creating an explosive release of energy akin to a nuclear weapon.

The UK stores the world's largest civilian plutonium stock at Sellafield, where plutonium is looked after by an armed guard, the Civil Nuclear Constabulary. A number of organisations, including the NDA, the Office for Nuclear Regulation (ONR) and the Environment Agency (EA), are responsible for the regulation and safety of plutonium storage. The UK Government's policy for plutonium "is to provide a solution that puts the vast majority of UK held plutonium beyond reach" (BEIS & NDA, 2017: 19). 'Beyond reach' is an ambiguous policy statement, and a range of technologies have been proposed, individually or as a combination, as possible methods for managing the UK's plutonium stockpile. All proposals put forward thus far are based on tried-and-abandoned or untested-and-non-existent technologies. The UK Government's current preference for managing plutonium is to reuse it as mixed oxide fuel (MOX), but alternative, complimentary rather than exclusionary, solutions to the long-term management of plutonium have also been suggested. These include transmutation (POST, 2005), the reuse of plutonium as fuel in fast reactors (IMechE, 2013) and disposal. Whichever combination or individual technology the future management of plutonium relies on imaginations of brave new technologies and/or revisiting failed technologies of the UK's nuclear past.

Optimising the atom

Plutonium is divisive and divided. It is often imagined as two: reactor-grade or weapons-grade plutonium. While these plutoniums differ in their isotope composition, both present potential proliferation risks and need to be managed with that risk in mind. This duality is what makes plutonium such a difficult matter to define for the purposes of nuclear waste management or otherwise. Currently reactor-grade plutonium is defined as nuclear material, a zero value asset, as opposed to waste (NDA, 2010). Until the 2010s, the UK's official position was to store plutonium "indefinitely […] until 2120" (NDA, 2010: 9). Since then increasing pressure both nationally and internationally has been pushing for a more clearly defined long-term management strategy for the UK's plutonium stockpile and a decision on whether plutonium should be disposed of or reused. Optimism about the ability to optimise plutonium as an energy source together with concerns over proliferation, imaginations of nuclear apocalypses and utopias, have emerged as arguments against the disposal of plutonium. The desire to optimise the atom is not confined to plutonium solely, but characterises the UK's relationship with a range of nuclear materials. Colin, for instance, weighed the UK's nuclear future in relation to spent fuel.

> Coming back to the earlier comment about 'what is the future?', it may actually be that by 2050 spent fuel may actually not be a waste at all. It might just be waste in our time. And in the UK position that actually doesn't matter, because the first thing we're going to do is to store this stuff for a hundred years. […] The reality is that the UK will not be disposing of spent fuel until way after there is much more clarity about the nuclear future. (CoRWM member, interview)

Colin went onto note how the classification of spent fuel either as an asset or waste "makes no practical difference to the way any of it is managed at the moment". While the half-life and heat generation of spent fuel can be seen as fostering flexibility in the present (as decisions about the future of SNF need not be made imminently), they also foster indecision or enable the postponement of decisions about the future of the waste management, as we saw in section 6.2. With regards to plutonium, its potential as an energy source has prevented the

UK Government from articulating a clear long-term management strategy for the material, as suggested first by the policy of 'indefinite' storage, and second by the ambiguous aim of placing plutonium 'beyond reach'. A 2007 report commissioned by the NDA on the management of plutonium, while making no recommendation on management alternatives, considered disposal as the lowest risk alternative, but also posited that reusing plutonium could "release significant value from the material" (NDA, 2007: 15). Frank von Hippel and Gordon Mackerron have argued that the claim about the significant value of plutonium is not credible, but has been made without any "reviewable basis" (von Hippel and Mackerron, 2015: 18).

Yet the notion of plutonium's potentially 'significant value' echoes the early atomic optimism in the UK about the future utility of difficult nuclear materials. Following this 'historical' optimism, the UK Government laid out in 2011 its preference to manage and use the UK's civilian plutonium stock as MOX fuel (DECC, 2011). In a 2011 House of Commons debate Colin Hendry, Secretary of State for Energy and Climate Change, articulated this preference through the comparison of MOX and disposal technologies. The MOX option, Hendry posited was "the more technically mature [alternative], given that MOX fuel [has] been successfully fabricated and used in reactors in Europe, and given that by comparison no equally mature immobilisation technology [is] readily employable" (HoC, 2011, vol. 533, c.313). Unlike with GD, the UK has reasonable experience of MOX production. Sellafield produced MOX for over three decades to support the UK's FBR programme. The production of MOX continued even after the curbing of the FBR programme in 1994. In this sense the commitment to MOX over disposal as the long-term management method for plutonium can be seen as future making through business-as-usual (Urry, 2016). The House of Commons debate where Hendry defended the MOX option, however, took place against the closure of the Sellafield MOX Plant (SMP). The Plant was completed in 1997, but due to deficient design and a poor performance record, the NDA decided to close the plant in 2011. The SMP was designed to produce 120 tonnes of fuel out of the UK's plutonium stockpile per annum, but managed only five tonnes in its first five years of operations. While Hendry recognised the risks of the "reuse-as-MOX option, particularly given the poor performance of the Sellafield MOX plant" (ibid.), he associated the risks with the particular design of the SMP rather than MOX technologies more broadly. As he ascribed and confined the MOX fabrication failure to a particular facility rather than to the MOX production technology, the MOX option retained its validity (Brown and Michael, 2003).

The UK is not the only country that has struggled with MOX. Japan, France and the US, similarly, have faced challenges with MOX production. Based on experiences in the UK and more broadly, von Hippel and colleagues argued in a 2012 comment piece in *Nature* that

> [the UK strategy of reusing plutonium as MOX] is likely to run into technical and political difficulties, as well as escalating costs. [...] Britain should seriously evaluate the less costly and less risky method of direct plutonium disposal, and take the opportunity to lead the world towards a better solution for reducing stockpiles. (von Hippel et al., 2012: 167)

Unlike the UK Government, the authors of the piece see little benefits in the reuse of plutonium. Rather they advocate disposal as the better solution. Similarly, von Hippel and MacKerron (2015) have argued against MOX fuel holding that MOX is an unnecessarily costly solution for the management of plutonium. They posit that since plutonium-as-MOX lacks a solid economic rationale, MOX should be “regarded as a waste-disposal program” (von Hippel and MacKerron, 2015: 3). If MOX is thus just a more complex and costly route towards the eventual disposal of plutonium, von Hippel and MacKerron argue, then “there is every reason to ask whether alternative approaches could achieve as good a result at less cost” (ibid.). Joining these critiques, Neil Hyatt (2017) has argued against the sole focus on MOX for the long-term management of plutonium as risky. The UK industry, he claims, has thus far demonstrated little interest in a future MOX fuelled nuclear industry. He holds that “the commercial appetite for MOX […] is expected to remain weak” (Hyatt, 2017: 307). Both of the UK’s PWRs, the presently operational Sizewell B and Hinkley Point C yet to be constructed, have the technical readiness to use MOX fuel. However neither reactor is likely to begin accepting MOX. Sizewell B is not licensed for MOX use, while the Generic Design Assessment for Hinkley Point

C explicitly excludes MOX use from consideration (ONR, 2011). The UK Government's vision of MOX as the future for the management of plutonium is thus contested by the nuclear industry. Moreover, since the Government is not in a position to impose its MOX vision on the industry in practice, the Government's favoured strategy for the long-term management of plutonium through MOX can be argued to rest on utopian future visions.

Atomic optimism

The preference for MOX seems to spring from the same kind of atomic optimism that characterised early discussions of the management and utility of nuclear wastes and materials in the UK. The belief that profitable technological solutions can be found for the (by-)products of nuclear activities appears deeply rooted in the UK's nuclear imaginations. The notion of the malleability and transformability of nuclear products is at the heart of plutonium management plans. In part, the UK Government's desire to find uses for the UK's civilian plutonium stock can be seen to stem from the UK's desire to be a serious competitor in the nuclear market (Walker, 1999). William Walker (1999) has noted that when the military interest in plutonium production diminished, the UK Government put its faith in the development of the fast breeder reactor that would require large quantities of plutonium. As the UK failed to establish itself in the reactor market, its commitment to reprocessing strengthened. It was with reprocessing and the fuel cycle, rather than reactor technology, where the UK's market opportunities were seen to lay. MOX, thus, is the latest reincarnation of a decades' long desire to put plutonium to good use. In *Nuclear Entrapment*, Walker traces how in the 1990s the Thermal Oxide Reprocessing Plant (THORP) was given an operational licence at a time when the facility was already redundant. THORP was designed to reprocess spent oxide fuels and most of its customers were foreign nuclear operators. THORP was depicted as providing easy profit with foreign customers shouldering most of the operational costs, while the predictions of the UK's civilian plutonium requirements were exaggerated and intertwined with the fast breeder programme. Moreover, Walker notes, the licencing of THROP relied on the alleged superiority of reprocessing over the storage of spent fuel. Running through the story of THORP, he argues, is a failure to maintain diversity of technological alternatives to nuclear waste management. Reprocessing has been the UK's go-to waste management policy, and it was not until the 1990s that the Government and industry came to regard storage and disposal of spent fuel as an alternative to reprocessing, but even so disposal remained marginalised. Accordingly, Hyatt has argued for more diversity in the management of plutonium. He advocates a “dual track strategy” in which plutonium is either converted to MOX or prepared for disposal (Hyatt, 2017: 303). A commitment to such a strategy, he argues, would ensure that the UK would be better positioned to include plutonium in the nuclear waste inventory, and by extension to be better prepared for disposal, should the reuse of plutonium as MOX prove an unviable long-term management strategy.

Although the dual track strategy is not the UK’s official plutonium management policy, Arthur noted that RWM are obliged to demonstrate preparedness that it can engineer a suitable plutonium wasteform, in case the disposal of plutonium is added to the disposal agenda. While Hyatt has argued that disposal is the only alternative capable of addressing the entire civilian plutonium stock, von Hippel and Mackerron view that the absence of commercial immobilisation technologies for plutonium might make the serious consideration of the disposal of plutonium unlikely. Hyatt however points out that not all plutoniums are suitable for MOX conversion. Similarly, the Institute of Mechanical Engineers (IMechE) has observed that that the management of the UK plutonium stockpile is “more complex than was originally anticipated” (IMechE, 2013). As with the UK nuclear waste inventory, materials that need management under the plutonium banner are multiple, varied, and complex. Aside from the military/civilian designation, there are different grades of plutonium that might require different kinds of treatment and, alternatively, have different potentials for future usage. IMechE’s for instance has proposed a three-track management plan for plutoniumu based on three different grades (high, low and poor) of civilian plutonium. Each grade would, in IMechE’s proposal, have its own management pathway. In the proposed management plan, high grade plutonium would be converted into MOX, while lower grade plutonium would be used in the PRISM[14] and poor quality plutonium would be disposed of in a GDF.

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[14] PRISM = Power Reactor Innovative Small Modular technology is a sodium-cooled fast reactor currently under development in the USA with a planned ability to burn spent fuel from conventional reactors.

IMechE notes that to realise this vision of plutonium management, the NDA would have to alter and invest in its plutonium classification system. Plutonium would have to be re-classified (Bowker and Star, 1999) according to grades and quantities of different types of plutonium. This would further require the NDA to demonstrate the potential range of grades applicable to the different management alternatives in order to identify appropriate management methods that best suit the plutoniums needing to be taken care of. Thus, the IMechE's more diverse, like the UK Government's more singular, vision of the management of plutonium requires significant technological development or the reintroduction of older technologies in order to be realised in the future.

The belief in the Midas-like ability of the industry to optimise the atom might impose further challenges on GD. Managing plutonium as MOX does not erase the need to implement GD or the need to dispose of plutonium in one form or another. The spent MOX fuel still needs to be disposed of. The management of plutonium through MOX might impose challenges for the construction and design of the GDF. MOX disposal has two notable disadvantages in comparison to plutonium disposal (Hyatt, 2017). Firstly, the heat output from MOX wasteforms is expected to surpass the heat generated by 'simple' plutonium or spent fuel wasteforms. This would expand the footprint of the GDF since MOX canisters would need to be placed further apart from each other than 'ordinary' spent fuel canisters to ensure that their combined decay heat will not fry and disable the multi-barrier system. The increased size of the GDF would hike up implementation costs and, more crucially, possibly render the siting process more challenging, as a greater volume of intact bedrock would be needed for GDF construction. Secondly, MOX disposal demands a geological environment with conditions that prevent the oxidation of uranium. Oxidation would make the uranium more mobile, more difficult to contain. While this is not seen by engineers to present an insurmountable challenge to GD, it is an important consideration in assessing the safety of GD (ibid.). Finally, MOX fuel is significantly more expensive than conventional nuclear fuels and, as we saw above, the UK nuclear industry is not invested or interested in using MOX in its reactors in the foreseeable future. Thus, while MOX fails to eradicate the need for eventual plutonium disposal, it generates further concerns for GDF safety considerations.

Limited waste management alternatives

Through plutonium, and reprocessing, we can trace some of the more prominent challenges of the UK GD project. Reprocessing has, in the first instance, fostered a narrow approach to nuclear waste management (Walker, 1999). Additionally, it has ensured that nuclear waste management depends on highly rigid material practices. The materiality of nuclear wastes from reprocessing introduces a level of inflexibility to the UK's GD project. Reprocessing generates a range of nuclear wastes and materials that, if not reused, need to be treated and immobilised before disposal. Immobilisation of this waste in an engineered wasteform is necessary because of its material form. High level wastes, for instance, mainly exist in a liquid form, while plutonium is stored as powder. The UK's range of waste is incorporated, immobilised, in carefully chosen materials. Cement for ILW, glass for HLW, glass-ceramics for plutonium residues and plutonium contaminated materials, and ceramics for plutonium – if plutonium was to be disposed of. The merging of nuclear waste and materials of containment creates new material entities: wasteforms. These wasteforms mesh nuclear wastes and mundane durable materials on the atomic level in irreversible ways. When HLW is vitrified, mixed with borosilicate glass, it becomes so entangled with the glass that teasing it out from the glassy wasteform is comparable to removing the pigment of a dyed glass. The glass and HLW assemble in an inseparable way. The same will apply to ceramic plutonium wasteforms, if the decision is made to immobilise plutonium and emplace it in the GDF. The very concrete entanglement of nuclear waste with materials of containment on the atomic level (Chapter 5) removes any potential there may be for reverting wastes back into useful materials. Once plutonium is put in, there is no taking it out of the GDF. The irreversibility of these material entanglements reduces the flexibility of the GD project and the GDF design in ways that maintain uncertainty in the final disposal inventory. The irreversibility of immobilisation can be seen as a affecting the UK Government's willingness to commit materials to disposal, where these materials might have potential future uses. While waste classes themselves are flexible and mutable, once a material has been declared and treated as waste, once it has been immobilised, there is not an easy way to reverse the decision. This may go some way in explaining the UK's unwillingness to commit nuclear materials to disposal. The rigidity of wasteforms, the need to engineer new assemblages for the containment of waste maintains open-endedness that in purely GD terms is potentially unhelpful.

Classifying a material as nuclear waste requires certainty about the material, namely a judgement of its future usefulness or uselessness. Because of the material forms of UK's nuclear wastes and materials, decisions about the futures of these stuffs need to be taken well before disposal. The composition of wasteforms additionally renders the engineering of retrievability, the ability to retrieve nuclear waste packages from the GDF, redundant. In the UK, the policy position on the irreversibility of GD is clear. In the 2014 White Paper, DECC made it clear that the GDF will provide a permanent solution to the long-term management of nuclear waste in the UK and that the "purpose of a GDF is to dispose of waste, not to store it" (DECC, 2014a: 5, 24). The imagination of GD as a permanent solution to the long-term management of nuclear waste requires that clear, irreversible decisions about what counts as waste and what does not need to be made before disposal commences. This rigidity and irreversibility of waste categorisation imposed by the UK's waste treatment practices and the commitment to disposal as a permanent waste management strategy might hinder the implementation of GD. Reprocessing, the production of wasteforms, and the imagination of GD as the 'end point' for nuclear wastes leave the UK's GD project intolerant of flexibility and unable to accommodate technopolitical uncertainties and indeterminacy.

In the following section I will return to the Finnish case, and explore how the notion of retrievability, excluded from the UK's disposal plans, has shaped the implementation of GD in Finland, and how it has informed the understanding of GD as a permanent solution to the nuclear waste problem.

6.4 Fiddling with the finality of disposal

In *The Bedrock of Opinion*, Göran Sundqvist proposes that "those who argue for reprocessing […] consider spent fuel to be a resource, while those who argue for a final storage of all spent fuel view it as nothing but waste" (Sundqvist, 2002: 8). Such a clear-cut definition of waste, however, is potentially problematic. Spent fuel in particular escapes easy definition. While Sundqvist's assertion seems applicable to the UK's case, where waste classifications and definitions need to be finalised and cemented before disposal, the inclusion of *retrievability* in a disposal concept challenges such neat binaries as waste and asset. Retrievability, that is, the ability to bring wastes back to the surface after they have been disposed of in the GDF, was included in the Finnish GDF design in response to public and parliamentary debates on retrievability during the siting process (Lehtonen, 2010).[15] Markku Lehtonen notes that the demand from retrievability emerged from local concerns in Loviisa that was in contention to become a disposal site, while a survey conducted by a regional newspaper revealed that the majority of Finnish parliamentarians were in favour of retrievability (ibid.). The inclusion of retrievability in the Finnish disposal concept has been underlined as a rare outcome from public participation in the siting process (Hokkanen and Kojo, 2003). Opponents of the GD project have argued that Posiva used retrievability to legitimise the GD project without addressing or changing the design or basic principles of the disposal concept (Rosenberg, 1999). By including retrievability in the disposal concept, Posiva could demonstrate that it had listened and acted upon the criticism laid against GD by opposing groups. Thus, the inclusion of retrievability has ensured and insured Posiva's original concept as the one that will be implemented.

From a democratic and governance perspectives, the inclusion of retrievability closed down controversy and spaces of debate. Where Posiva can be seen to have appropriated public concerns to support an already existing waste management solution, the inclusion of retrievability in the concept can also be read as introducing flexibility to waste definitions. This ensures that GD does not rely on such rigid waste classifications as it does in the UK.

The Finnish disposal culture understands retrievability as a techno-economic

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[15] Retrievability is part of the French and Swiss disposal concepts, but not the current UK one.

issue, and through the ability of spent fuel to flow between waste and resource classifications. Retrievability is mainly conceptualised through the acquisition of potential revenue from spent fuel in the future. STUK describes retrievability as a mechanism that offers future generations the chance to manage nuclear wastes in a more “rational and economic manner” (STUK, 2001) in case advancements in waste management technologies were to allow this. This statement is underscored by the notion that ‘waste’ is a temporal class. The unavailability of reprocessing technologies in Finland forced the classification of spent fuel as waste in the early 1980s. By the same token, were new alternatives for the management and/or use of spent fuel to emerge the waste designation could be reversed and spent fuel reclassified as a resource. The Finnish branch of Greenpeace (2008) has criticised this techno-economic foundation of retrievability for the failure to acknowledge that the retrieval of waste might be needed as a safety measure to prevent radioactive leaks or to retrieve damaged waste canisters.

Once disposed of, spent fuel in official imaginations, it seems, is conceptualised only through its ability to unbecome waste and to become a resource. Its liveliness, mobility and ability to pose a threat to safety through leakages are ignored. Indeed, in 2001 MTI asserted that the “need for retrieval because of safety reasons seems extremely unlikely” (MTI, 2001: 6). Highlighting technological development rather than safety as the potential primary cause for retrieval reflects a belief in engineering to offer solutions to ‘wicked problems’ such as nuclear waste management (Demos, 2010). Technological failure does not feature in imaginations of retrievability. Additionally, the notion of retrievability contributes to representations of nuclear waste as controllable through GD. Imaginations of the passivity and tameness of spent fuel are at the core techno-economic notions of retrievability. The Finnish vision of retrievability describes spent fuel through passivity and pacificity. Rather than a lively and a corrosive material, spent fuel is depicted through stillness, its slow decay towards harmlessness, or alternatively its readiness for retrieval and potential reuse.

The inclusion of retrievability renders the GDF ontologically ambiguous. Where STUK’s Nuclear Safety Board posits that retrievability “must not jeopardise long-term safety or increase the likelihood of intentional or unintentional human intrusion in to the GDF" (STUK, 2000: 6), Vira from Posiva has noted; "based on the Decision-in-Principle on final disposal, we, in fact, are not allowed to try to prevent people from intruding into the GDF" (Posiva, 2010a: 3). Similarly, Markku, an engineering professor, noted that the multi-barrier system "cannot be too big of a barrier for future generations who might want to reuse nuclear waste". While MTI denied the necessity for waste retrieval due to safety reasons, it held that retrievability "may in the future be considered necessary, for instance, if transmutation technology leaps forward significantly" (MTI, 2000: 9). Echoing this Olli Rehn, Minister of Economic Affairs, in a parliamentary debate over Posiva's CLA noted that if "during the upcoming decades a better solution is found [for the management of spent fuel], the doors have not been closed to it" (PTK 62/2015: 10). The temporality of GD as the best *available* solution is recognised by Rehn and MTI alike. Yet the *potential* emergence of a better nuclear waste management solution in the future is not seen to justify the leaving of waste aboveground in the present. In a 2010 newsletter Posiva asserted that while "technology will undoubtedly develop from here, waiting for the future is not a solution" (Posiva, 2010a: 3). As we saw in Chapter 5, the aboveground is constructed as a *riskier* space than the underground (Williams, 2008).

Where the 1987 Nuclear Energy Act posits that "nuclear wastes […] must be disposed of in a permanent manner" in Finland (Nuclear Energy Act 990/1987), retrievability muddles that permanence and leaves an opening for alternative waste management futures, even if these futures are not readily embraced. Posiva, in its 2015 CLA, notes that possible future developments in nuclear waste management technologies might make the retrieval of spent fuel an attractive option in the future, yet the GDF design does not include aspects that enhance the retrievability of nuclear waste (Posiva, 2012). This, Posiva posits, is due to safety reasons and STUK, similarly, maintains that the "retrieval of waste canisters, if needed" should be possible "with the technology available at the time of disposal and with reasonable resources" without compromising safety (STUK, 2000: 6). Although explicit arrangements for retrievability are not included in the GDF design, the prevailing view within the Finnish disposal culture is that, at least in principle, "retrieval is always possible […] but that it could incur significant costs" (Lehtonen, 2010b: 146). Nonetheless, by 2015 retrievability had become a "central criterion of the disposal concept" in technopolitical imaginaries (PTK 62/2015: 10).

In the Finnish '*final*' disposal project, the very idea of finality has been blurred to make way for the implementability of GD. Retrievability blurs the waste/asset and the disposal/storage binaries. Samuli reflected that where the Egyptians buried pharaohs, the GD project "buries energy sources underground". Similarly, Markku held that future generations must be given the chance to "reuse nuclear wastes and exploit their energy of which only a fraction has been used. I believe they will be used many times over, they aren't waste but a resource". Ulla, similarly weighed that "spent fuel is very valuable. It would be most sensible to extract reusable elements from it […] but it's expensive and insensible in Finland in the present situation, a probably during the next few millennia as well". "If we really think about it", she noted, "we are disposing of vast amounts of reusable material".

In this sense the Finnish disposal culture imagines spent fuel as *both-and.* Even after disposal spent fuel's waste status is ambiguous. This diverges greatly from the UK's *either-or* conceptualisation of spent fuel. In the UK, aboveground spent fuel can be either an asset or waste, underground it is just waste. The acknowledgement of the temporality and indeterminacy of matter, the discursive, if not necessarily engineering, openness to retrievability and uncertainty of matter might well be what enables GD to move forward. Timo Seppälä, Posiva's communications officer, has noted that retrievability "has not been insignificant for the progress [of the project]" (Seppälä, 2001: 6). Retrievability, he observes, is a question that emerged time and again in parliamentary debates.

> People avoid making "final" decisions. Thus retrievability offers an official route for cancelling final disposal. Moreover, it offers future generations the opportunity to evaluate the sensibility of the solution we are planning now. (ibid.).

From this perspective, fiddling with the notion of finality, avoiding rigid boundaries between storage and disposal, asset and waste, have influenced the implementation of *final* disposal. Although from an engineering perspective, Posiva might merely be paying lip service to retrievability, as no particular provisions for the retrieval of waste are being implemented, the Finnish disposal culture appears relatively willing to embrace uncertainty, if, as in the case of retrievability, this is seen to facilitate the advancement of the GD project. The Finnish disposal culture acknowledges the potential temporality of disposal (Hetherington, 2003) and the indeterminacy of waste (Hird, 2012). These are not seen as challenges to the implementation of GD, which, even with retrievability is considered “a better way to protect humans and the environment from nuclear waste than aboveground storage demanding constant oversight” (Vira, 2010: 3). By acknowledging the potential becomings and unbecomings of waste and disposal, the Finnish disposal culture seems willing to embrace uncertainty at least to a certain extent as a way of taking the GD project forward.

6.5 Summary

In this chapter I traced some of the ways in which the policy ‘finality’ of GD and its implementation have been challenged in both the UK and Finnish disposal cultures. In the first two sections of the chapter I observed how imaginations of disposal futures remain dominated by short-termism, although in both cases geological time has been mobilised to envision and plan disposal futures. In Finland, *the beginning of disposal* has been imagined as *an end point* towards which the implementation process is progressing. While this short-term vision of the GD future has enabled the crafting of a success story, concerns have risen that the emphasis on engineering and constructing the GDF might jeopardise long-term safety, as less resources are committed to safety research. In the UK, on the other hand, the rush to implement GD in the first instance, and the subsequent pushing of disposal future deeper into the future, may have harmed subsequent attempts to implement GD. Where in Finland the disposal project has been structured based on the half-lives and heat generation of spent fuel to identify the earliest possible disposal date, in the UK half-lives have been mobilised to justify inaction and postponement of decisions on the disposal front.

In the second half of the chapter, I explored waste imaginations through reprocessing, MOX and the notion of retrievability. What emerged here were significant differences in the ways in which uncertainty and the indeterminacy of waste are accommodated by the UK and Finnish disposal cultures. In the UK the notion of the permanence of GD, and by extension the definition and classification of waste, is much more rigid and than in the Finnish case. The Finnish disposal culture seems more prepared to accommodate the indeterminacy and temporality of both wastes and disposal. Letting go of a narrow definition of finality and permanence, and accepting the changeability of wastes, policy, and disposal, seem to have been vital in the progress of the Finnish GD project. In contrast, the UK's indecision as around the disposal inventory, and the need to decide and stick to waste definitions as final, seems to discourage the making of decisions about waste, preparing immobilisation solutions to ambiguous materials such as plutonium, and further uncertainty about the disposal inventory might discourage communities from volunteering to host the GDF.

Miller has argued, "without the opening up of our imaginations to the deep future, we will lack the capacity to grasp our deep responsibility" (Miller, 2016: 437). Short-termism in the makings of disposal futures diminishes the sense of responsibility for the deep future, which can then be postponed or be treated in an unequal relationship with the present. The UK and Finland relate to notions of the future and finality in different ways. The UK has been more prone to rush to implement GD, which has resulted in the GD project receding deeper into the future. Finland, on the other hand, took a slower approach to the implementation process, and is closer to beginning to realise the disposal future. Finland also appears more willing to embrace the uncertainty and ambiguity of disposal and waste categories than the UK does. The UK's *either or* approach, either waste or asset, either disposal or storage, emerges in contrast to the Finnish *both-and* approach to GD. In Finnish imaginations, disposal can be(come) storage, and waste can be(come) an asset. This both-and approach to GD, the blurring of binaries and the notion of finality may be important factors in the 'successful' implementation of GD. The UK's more rigid approach to categories, on the other hand, may risk the continued presence of hazardous nuclear materials in interim aboveground storage facilities. In both countries disposal futures have been contested and questioned through and because of their short-termism.

7 MAKING CONTAIN-ABILITY

> We're forever teetering on the brink of the unknowable, and trying to understand what can't be understood.
>
> \- Isaac Asimov, *The Caves of Steel*

A central concern of this thesis has been to trace ways in which the UK and Finnish disposal cultures make and envision safe futures through the geological disposal of nuclear waste (GD). These countries were chosen for this study since they are both different and similar enough to enable interesting, yet disciplined, contrasts and variations to emerge from the research (Jasanoff, 2005). In doing so, the UK and Finland have enabled me to highlight some of the issues, 'successes', struggles and concerns that relate to the making of very distant futures through GD.

In the first part of this thesis, I outlined my research problem, built a theoretical and conceptual framework for the thesis, and described how I proceeded to answer my research questions:

- How has nuclear waste been imagined in the Finnish and UK disposal cultures?
- How is safety made, into the deep, uncertain future?
- How are geological disposal, and the future, imagined within the Finnish and UK disposal cultures?

In building the theoretical and conceptual framework for this thesis in Chapter 2, I mobilised the past, the already known, in an effort to create something new. Like practices of future making, this thesis does not emerge out of nowhere, but is rooted in existing work. In Chapter 3, I reconceptualised participant-observation as body-work (Myers, 2008), as a way of relating with a range of human and nonhuman actors during and through data collection. Immersed elbow deep in the field with a respirator glued to my face at times, I was better able to follow the whole range of actors and processes I was interested in – but also better able to appreciate the role of nonhuman actors and the ways in which scientists relate to their at times toxic materials in the lab. I also introduced *disposal cultures* as a 'comparative-conversationalist' method for treating the UK and Finnish cases together-apart (Barad, 2007). The aim was to bring the two cases into a conversation rather than a direct comparison with each other.

In the second part of this thesis I mapped the trajectories of the UK and Finnish nuclear establishments and disposal cultures towards the implementation of GD (Chapter 4). I traced how nuclear waste has been problematised, re- and deproblematised by the UK and Finnish nuclear establishments and disposal cultures. I also traced some of the ways in which the deep future and safety are negotiated and made through relational doings in the present, both in field and in the lab as well as in public documents and statements on GD (Chapter 5). Finally, in the penultimate chapter of this thesis, I explored some of the ways in which the UK and Finnish disposal cultures relate to the future and the notion of finality, and how these relatings influence the making of safety into the distant future.

In this concluding chapter, I will synthesise the main arguments I have made in the thesis and offer my contributions to the wider field of STS. I will focus the final chapter around the issue with time. Time has been the thread running through the thesis. Time is accompanied by uncertainty and change. The longer the timeframe, the more space there is for uncertainty and change to emerge. In order to make safe futures GD projects need to manage and control time and its effects. Therefore, in section 7.1 I return to the challenge the very long lifespan of nuclear waste imposes on the making of safety and safe futures in the present. Here, I propose that the greatest differences between the UK and Finland emerge from the ways in which they construct and relate to the future and the notion of finality. I further propose that these relatings are affected by the materiality of nuclear waste inventories and imaginations of the possible future value of nuclear materials. In section 7.2 I discuss safety as emergent of situated makings. I posit that rather than a property of GD, safety and safe futures are made in contrast and in relation to something other than the proposed disposal concept. In section 7.3 I introduce the notion of *contain-ability* as a means to better discuss and conceptualise the temporality and contingency of the making of very distant futures through GD. I propose that sensitivity to the *temporality*, as opposed to the claimed finality, of disposal might be vital for the implementation of GD.

7.1 Discrepant times as the problem

"Since objects don't float in an infinite void", Tim Morton writes, "every entity has its own time, both in a physical and in a deep ontological sense" (Morton, 2013: 66). GD brings together a range of such times that are radically different. The short span of human existence is in a drastic contrast with the exceedingly long half-lives of nuclear waste. The multi-millennial radioactive risk extends beyond our ability to engineer and know things. While the future of nuclear waste stretches to times we cannot know, it is this same distant nuclear waste future that stretches backwards to the present, impelling societies to act in uncertainty in the name of the safety of future generations. The risk imposed by nuclear waste in and on the future is considered to be too great not to be addressed in the present. Yet, because of the discrepancy between human and nuclear times, Morton (2013) notes, it might be impossible to manage nuclear waste 'just right'. This discrepancy between human and nuclear times gives rise to the major challenge in the implementation of GD. While humans run out of time to fully know and learn about nuclear waste, the waste has to be somehow handled and managed anyway. The making of safe futures through GD thus rests on best available knowledge and knowhow in the present without much certainty about the accuracy of that knowledge deep into the future. This notion of the unknowability of the very distant future and the related concept of GD as a 'sociotechnical experiment' (Bergmans, Landström and Schröder, 2014; Schröder, 2016) provided the stating point for this thesis and the aim of this thesis has been to explore how the UK and Finnish disposal cultures make safe futures through GD in this context of uncertainty.

The nuclear waste problem is a problem of time, even more so than a problem of radioactivity. Nuclear waste is so massively distributed in time that it is impossible know fully. Nuclear time belittles human time, as the fleeting human existence is in stark contrast with the slow, long now and the very distant future of nuclear waste. It is time that set limits to knowledge production and attempts to predict the future of GD. As we saw earlier present-day modelling tools cannot deal well with very long timescales of GD, which means that uncertainties about the functioning of the GDF remain at the time of implementation and for millennia afterwards. In the lab, time is sped up through mundane material means to bring the deep future closer and to render it more predictable. Yet, while in the lab speeding up time is vital for providing the basis for safety claims and predictions about the future, GD itself seeks to slow down time to provide and maintain safety into the deep future.

GD as technology of stagnation

We can think of GD as a *technology of stagnation*. GD seeks to prolong society's capacity to control nuclear waste and uncertainties by slowing time down, resisting novelty and drawing from the past.

The first move in the long-term management of nuclear waste is the relocation of waste. Moving waste from the aboveground to underground is an explicit effort to slow down time and prolong control over nuclear waste. The underground and nuclear waste are more equivalent than nuclear waste and the aboveground are. The *slowness* of geological processes underground is juxtaposed with the *faster* pace of environmental, climatic and societal events and processes aboveground. Through this juxtaposition, the underground is constructed as a (more) predictable space than the aboveground. The former is characterised by stability and continuity, whereas the latter is depicted as an (more) unpredictable and disruptive space due to the faster passage of time, the relative rapidity of change, aboveground. In this sense, safety is crafted as the function of the relative passage of time. The slowness of life underground is seen as a greater provider of safety than the changeable and faster pace of life aboveground.

Secondly, the making of safe futures through GD relies on the past. The past, archaeological and geological evidence, is mobilised to predict and make safety claims about the future. Familiarity rather than novelty and innovation are positioned at the core of safety. Historical knowledge, gained for instance through archaeological evidence, of the behaviour of materials is projected into the future in order to predict how materials might evolve in distant times. The familiarity of the materials used to engineer the EBS is positioned as a *fundamental* safety principle. The familiarity of these materials (ceramics, copper, clay, iron, granite in the Finnish case) and the long joint history they have with humans is seen to render the materials *predictable*. There is more data and experience of familiar, historical, materials such as copper than of more recent and innovative materials.

Additionally, the idea of safety barriers itself is old. Different configurations of "barriers have been used to protect humans and property from enemies and natural hazards since the origin of human beings" (Sklet, 2006: 494). The idea of safety barriers has evolved from "barriers used to defend a medieval castle [that] mostly were of a physical nature [to] the modern principle of defence-in-depth [that] combines different types of barriers—from protection against the release of radioactive materials to event reporting and safety policies" (Hollnagel, 2016: 71). The multi-barrier system of the GDF seeks to moderate, even if not match, the longer now of nuclear waste, and in doing so provide protection against the release of nuclear waste and radiation. Thus the envisioned function of the EBS is two-fold. In the first instance, it aims to provide defence-in-depth through the redundancy of barriers. The failure of one barrier should not affect the safety provision of the entire system. In the second, the aim of the system is slow down time and movement both in and out of the GDF, be it groundwater or human intrusion or escaping radionuclides.

As we saw in Chapter 5, both the international nuclear waste community and social scientists appreciate containment as a temporal category despite the representation of GD as a 'permanent solution' to nuclear waste management. Instead of offering foreverness, GD seeks to stagnate and slow time down. GD is not envisioned to provide technical containment forever, but for *long enough*. One of the GDF design objectives is to ensure the *safe failure* of the facility. Where safety is ''nearly always defined as a condition where nothing goes wrong and a safe situation as ''marked by the absence of accidents and incidents" (Hollnagel, 2014: 12), in GD safety and failure are not easy opposites. Safe failure is a function of time. It is about slowing down the unavoidable decay of the EBS. Safe failure stands for the failure of the EBS *after* the levels of radioactivity in the disposed of nuclear waste have decreased to harmless levels. Safety is, thus, tied to the GDF's ability to stand against time and its corroding and eroding affects. GD therefore seeks to make and maintain safety by managing time and uncertainty. In order to do this, the material configuration of the GDF draws from the past to project possible courses of material evolution and behaviours into the future. By drawing on familiar materials, the past, the geological evidence and the age-old multi-barrier safety concept, GD projects seek to render the future predictable. Whereas novelty is seen as a potential source of uncertainty, familiarity and the past are mobilised in the making of safe distant futures.

Distance to the future

The very long lifespan of nuclear waste enables various imaginations of the future. As we saw in Chapter 6, the UK and Finnish disposal cultures relate to time and the lifespan of nuclear waste in different ways. This has influenced the ways in which they have related to the disposal future and how they have structured their GD projects in the past.

In the UK, the lifespan of nuclear waste projected into the future was mobilised to justify the postponement of action for half a century, whereas in Finland the very same lifespan was used as a foundation for the implementation of GD. The lifespan of nuclear waste has thus been utilised in different ways by the two disposal cultures. In the UK it was used to push the implementation of GD deeper into the future, while in Finland the lifespan of nuclear waste was mobilised to bring the disposal future closer to the present. Where long distance to the future, such as created by the UK disposal culture, can diffuse urgency and discourage action, a shorter distance to the future may imply more immediate effort (Michael, 2000). Different distances to the future, Michael (2000) writes, suggest different levels of ‘do-ability’. It is easier to achieve something within a decade than a century. The nearer the future, the more do-able and more in need of action it may seem.

The logic of earliest possible disposal and the imagined immediacy of the disposal future have driven the GD project forward in Finland. While the project has remained reasonably well within its original timetable the imagined short distance to the disposal future has produced its own problems. Some Finnish scientists have expressed concerns that the objective of the GD project has become blurred over time. Their concern is that the construction of the GDF has taken priority over the underlying science and safety research. The fear is that the implementation process has become more about completing an engineering project than providing safety into the deep future. Thus the different visions of the distance to the future by the UK and Finnish disposal culture have had differing effects from procrastination to, perhaps, a rush to meet the future. Both disposal cultures, despite their different approaches to the future, demonstrate some difficulties of relating to the very distant future.

Blurring finality

The international nuclear waste community envisions GD as the end point to nuclear waste management. Yet the UK and Finnish disposal cultures relate to this notion of finality in different ways. The UK's more rigid reading of the idea of finality emerges in contrast with the more flexible approach displayed by the Finnish disposal culture. The differing approaches to 'finality' tie in with the classification of nuclear materials as waste or an asset. Here again, the UK's approach emerges as more rigid, as nuclear materials are categorised either as waste or asset, whereas in Finland nuclear waste is imagined as both-and; it can still have future uses and value even after disposal. Thus, decisions about waste do not necessarily follow the politics of value in unproblematic or straightforward ways (Gille, 2010). The difference between the UK's *either-or* and Finland's *both-and* readings of nuclear waste can be traced, at least in part, from the materialities of their waste inventories.

In the UK reprocessing has created a range of nuclear wastes and materials that, if not reused, need to be treated before disposal. What this means is that nuclear wastes are meshed together with mundane durable materials (cement, glass, ceramics) to create disposable wasteforms. In wasteforms waste and materials of containment entangle on the atomic level in a technically irreversible way. This deep meshing of materials removes any possibilities of reverting waste back to asset. In this way, the materiality of the UK waste inventory and the need to treat nuclear waste before disposal reduces the flexibility of the UK's GD project and limits the space for alternative futures. While waste classes themselves are flexible and mutable, once a material has been declared waste and prepared for disposal, there is no easy way to reverse the decision. Because of the materiality nuclear wastes and materials, decisions about the futures of these matters need to be made before disposal. The irreversibility of waste decision and the *atomic optimism* of the UK government to find uses for materials with some potential future utility can be seen to undermine the UK Government's readiness to commit materials to disposal and clearly define the inventory for disposal. This in turn maintains uncertainty about the inventory, and can potentially delay, if not the beginning of disposal, then the closure of the GDF.

In Finland the potential for post-disposal alternative futures for nuclear waste is much greater. Spent fuel, which constitutes the whole disposal inventory, is in a readily disposable form and needs no special treatment prior to disposal. This facilitates the potential for its retrieval and reuse in the future. The retrieval of waste from the GDF post-closure offers a route for reusing waste, but also for cancelling GD. Retrievability is seen to offer future generations an opportunity to re-evaluate GD as a long-term policy without imposing the burden of active (aboveground) nuclear waste management on them. Thus space is left for the utilisation of possible technological advancements in the treatment of nuclear waste without actually waiting for those advancements to emerge. The Finnish case suggests that the implementation of GD might well rely on the blurring of the notion of 'finality' and allowing the 'final' to become temporary.

Through retrievability disposal always has the potential to revert to storage, and waste to asset. Retrievability underlines the temporality and indeterminacy of disposal, as well as waste classifications. Rather than definite categories, disposal and waste are viewed as temporary classes with the potential to become something else. In contrast to the UK disposal culture, the Finnish one seems more willing to accept and implement a disposal solution that might in time become a means for ensuring that waste is *at the disposal* of future generations than that is disposed of permanently. In this sense, the Finnish disposal culture emerges perhaps *more* inclined to embrace uncertainty as a way forward than the UK disposal culture does.

7.2 Safety as relational makings

GD has been proposed and promoted as the best available (e.g. EC, 2011; NEA, 2008) or the *least worst* option (Corkhill, 2017) for the long-term management of nuclear waste. We can read GD as an attempt to create more equivalence between the discrepant human and nuclear through delegation (Latour, 1992). GD is an attempt to exert and extend control over waste beyond human ability by delegating safety to the GDF and the underground. It is an attempt to make society durable (Latour, 1990) in space and time; and to ensure the safety and security of the living world (Massart, 2013). The international nuclear waste community imagines safety and GD almost as synonyms. While Posiva's slogan reads '*only safe disposal is possible*', the RWM (2016c) visions *a safer future* through GD. Thus in the imaginations of nuclear waste management organisations GD, safety and the future appear in close association. GD is safe; GD is (in) the future.

Safety, however, is not a property of GD. It is argued, negotiated and made through relational doings. Future making through GD contrasts and compares the times of different spaces and entities in order to make a case for long-term safety. Geological processes and the underground are contrasted with societal, environmental and climatic events of the aboveground. In contrast to life aboveground, life underground is described as slower, more stable and more predictable – particularly in the very long-term. The extended, yet calmer, liveliness of the underground in time and space, in contrast to the faster-burning and more changeable life aboveground, the international nuclear waste community argues, makes the underground better able to meet and mediate the very long future of nuclear waste. The making of safety relies on 'world-reduction' (Jameson, 1975); it relies on separations between nature and culture, the underground and the aboveground. These separations enable the contrasting and comparing of different spaces – and the making of safety. Aboveground societal and climatic changes are faster – even when we talk about glacial cycles. Where glaciation disrupts life aboveground, it is not expected to significantly affect the underground. In contrast to the scarring of the aboveground, the underground is expected to survive glaciations without major changes to underground conditions. Through the comparison and contrast of aboveground and underground spaces, events and processes the underground is established and presented as *safer than* the aboveground. Although the underground is presented as *safer than*, it is not an uncontested or an unambiguous space.

The underground itself emerges in this thesis as a malleable and negotiable space. In Chapter 5, I traced how the envisioned safety of granite and clay environments have been contested and contrasted. UK and US researchers (neither country envisions disposal in granite) have described granite as a risky space in the long-term. Particularly fractures, characteristic of old granites, have been considered as what I have termed *spaces of risk*. In granites all movement is governed by fracture networks. As conduits for movement, fractures can pose risks to containment and safety. They can offer groundwater ways into the GDF. When groundwater encounters the EBS, it imposes its erosive and corrosive influence on the EBS, slowly decaying and disabling the ability of the EBS to contain nuclear waste. Where fractures offer ways into the GDF, they also offer ways out – escape routes for the waste when the EBS has failed. Thus, fractures enable movements both in and out of the GDF, thus placing the GDF's ability to contain nuclear waste at risk.

In contrast to this reading of fractures as spaces of risk, the Finnish disposal culture has renormalised (Barad, 2007) these spaces as *spaces of predictability*. The very fractures and age of the granite that others have described in terms of risk and uncertainty have been translated as sources of predictability and stability. Because all movement in granites is channelled to fractures, movement is contained in particular spaces. Safety can be engineered by avoiding and working around these spaces. The perceived predictability of risky movement in specific spaces is mobilised as a safety argument.

Spaces of predictability and the safety provided by these spaces, relies on the notion of the cyclicality of geological time. The predictability of underground future (as opposed to future aboveground) rests on assumptions that past geological processes will be repeated in the future. The assumed cyclicality of geological processes is utilised to tell stories about the safety of GD in the future. The cyclicality of geological time and processes, the assumption that what has happened before will happen again in the same spaces as before, together with the linear time and steady process of radioactive decay are mobilised to make the case for the safety and predictability of the deep future and GD.

7.3 Temporality of containment

Official representations of GD, as we saw in the Introduction, describe GD in terms of permanence. We can read in GD the need to demonstrate containment (Kinsella, 2001) and control (Mackerron and Berkhout, 2009) that has dominated nuclear operations internationally. Containing nuclear waste in the GDF is a promise of continuing safety and security. Containment of nuclear waste is desired, anticipated, expected, even projected, but never certain, never verifiable. Containment can be located in the 'non-factual future and the realm of ideas' (Adam and Groves, 2007). While containment might become proven as a fact in due multi-millennial course, we will never have certainty about containment. Rather, it remains an idea, or perhaps more accurately, an ideal.

As we saw earlier (in Chapter 5), the most certain thing about GD is that containment will fail. The temporality of disposal, the ability of waste to escape containment is well established in social science literature (see e.g. Hetherington, 2004; Hird, 2013a). Waste has the ability to flow (Gille, 2013) even when contained, and to form new entities within the disposal environment (Hird, 2013a). The longevity of nuclear waste ensures that waste cannot be kept in place 'forever', and van Wyck (2005) has described nuclear waste as 'matter without a place'. Its containment can only ever be temporal. This 'reality' of the waste's long lifespan, as we have already seen, sets parameters for the making of safe futures through GD.

The multi-millennial half-lives of nuclear waste, together with international standard practice for GD safety assessment, have created, what I have called in this thesis, the deep future of GD. The deep future, the timeframe for GD safety assessment, has been cemented to one million years. This timeframe challenges existing engineering and knowledge making practices and capabilities, and even sections of the international nuclear waste community have questioned the meaningfulness of this timeframe. There is much uncertainty about the reliability of predictions, calculations and models that are being made about the very distant future in the present. The deeper into the future GD cultures seek to map their projects and the evolution of the GDF, the less verifiable the models and calculations become and the more unpredictable the future. Samuli, a Finnish PhD student, weighed how “modelling tools run out capacity fast. If we put in as detailed data as we observe in the bedrock, we would never get any results. A computer fails much faster than we are able to input that level of detail into the model”. Thus by necessity and in order to make any predictions about very distant times disposal cultures engage in world reduction (Jameson, 1975), and individual experiments and experimenters focus on a limited number of factors influencing and contributing towards safety. Predictions about the future are made through simplification and fragmentation of the systems on which safety claims rely. At the same time, these tools are pushed well beyond their routine operations to map and predict times and processes they have not been designed to deal with. The radical difference between nuclear time and present ability to map that time drives knowledge production practice to plains of uncertainty, even unknowability.

This unknowability of the deep future, tied to the long lifespan of nuclear waste, has led some social scientists to propose the conceptualisation of GD as a ‘long-term sociotechnical experiment’ (Bergmans, Landström and Schröder, 2014; Schröder, 2016), and thus to directly contest the international nuclear waste community’s representation of GD as the ‘end point’ for nuclear waste or as the ‘permanent solution’ to the long-term management of nuclear waste. The experimental nature of GD, these authors write, stems on one hand from the very longevity of the future that needs to be mapped and modelled. Knowledge about the actual workings of the GDF, whether it provides safety and containment, as designed and imagined today, will not be available for tens or hundreds of thousands of years (Bergmans, Landström and Schröder, 2014). While containment relies on the long-term functioning of the GDF, it also rests on the hope and anticipation that future generations will not meddle with the GDF; that they stay away from the GDF, as the present generation wants them to do in order to maintain containment (Schröder, 2016). Little certainty about the GDF’s ability to contain nuclear waste into very distant times is forthcoming in the present, and containment remains hypothetical for the necessary timeframe.

Contain-ability

Given this uncertainty, what I propose here is that instead of containment we should talk about *contain-ability*. Where containment implies immobility, stasis, and order, contain-ability is more open and sensitive to the contingencies and uncertainties of containment. The *ability* in contain-ability in the everyday use of the word translates to '*possession of the means or skill to do something*'. Ability, thus, signals something that can be made, gained, but also lost. It has temporal quality. Our means to do things can be squandered, wasted, while unused skills can rust to the point of uselessness, so that even if we wanted to do something we simply might be incapable to do so.

Contain-ability does not deny to possibility of containment, but underlines its temporality, unpredictability and unverifiability. As we know now, containment is not an inherent attribute of GD. Rather it is made through situated relatings and doings of the underground and waste, as well as understandings of finality. As we have seen further above, designing containment depends on the waste that requires containment, and the geological environment in which the GDF will be constructed. The ability of the GDF to provide containment is based on knowledge about the characteristics and quantities of waste, and the knowledge about the characteristics of the geological environment. Waste and geology set the parameters for making containment.

While the term contain-ability underlines the temporal and experimental nature of GD, it also underscores this situatedness of making containment and safety into the very distant future. Where containment can be described in the abstract as a product of the GD multi-barrier system, contain-ability points to local configurations of the making of containment. It highlights the local contingencies and dependencies of safety and future making. Contain-ability highlights the negotiability of containment. Rather than a given property of the GDF or the EBS, containment is the possible product of a range of different sociotechnical configurations – as underscored by the observations that each disposal culture and GD project envisions safety and the future through (slightly) different means and configurations. While Matt noted that "the European nations and the USA are taking quite different approaches" to designing their GDFs, William argued that European nuclear nations are trying to "pretend that they share *enough* to make it worthwhile to collaborate, while in fact the […] disposal concepts are so different basically that there will be very little they have in common". The ability of the GDF to contain waste is thus the product of local doings that depend on available resources, geological options, the scale and characteristics of the disposal inventory and the ability of the disposal culture to make decisions.

Disposal projects speak of containment in certain terms. Containment is represented as something that *will* happen. In the 2014 *Implementing Geological Disposal White* Paper that laid out the most recent framework for the UK's GD project, containment is described as "achieved through the use of multiple barriers that work together to provide protection over hundreds of thousands of years. […] The multiple barriers […] provide safety" (DECC, 2014a: 19). Containment is treated as a matter of fact. What I propose, however, is that containment is what Wendell Bell and Jeffrey Olick (1989) would call 'an unrealised real present potential'. Bell and Olick note that much of science studies this kind of real present potentials or dispositionals. These real present possibilities can usually be detected by the suffixes descriptive of possibilities, such as '-able', '-ible' and 'uble'. Contain-*able*. As an example of a dispositional Bell and Olick provide us a glass:

> For example, a fragile glass may never be broken, but there is a real (present) possibility that it could be broken: it really *is* breakable. Studying such possibilities results in an empirical basis for warranted assertions about possible futures. (Bell and Olick, 1989: 122)

For the glass its breakability is real regardless of whether it breaks or not. Its breakability is a real unrealised present possibility for its future. With regards to GD, containment is such an unrealised present possibility. It is unrealised because no GDFs for civilian waste exist and thus the promise of containment has not been realised even in the short-term.[16] Because of the million-year timeframe, containment remains a possibility rather than a certainty. Because of the unverifiability of containment into the very distant, there can be no certainty that GDF actually will work the way it has been designed to do. In their discussion of futures, Bell and Olick distinguish between *real present possibilities* and *planned possible futures*. They note that real present possibilities are uncertain. They might or they might not occur in the future. In contrast, planned possible futures can be empirically tested. Containment on the GD timeframe is never assured. It cannot be planned based on empirically evidence and testing. There cannot be evidence-based certainty that the GDF will contain nuclear waste for as long as necessary.

More than anything else, *containment is an unrealised real present possibility of GD future making in the present*. The making of containment is reliant on the kind of situated practices and doings I have traced in this thesis. Containment is not a property of GD, but a locally crafted and configured ability of an engineered structure to contain nuclear waste for long enough. When we discuss GD as a form of future making, we should talk about contain-ability, about contingency and temporality, rather than about containment that signals certainty and 'foreverness', stasis and finality. Making futures through GD is as much about containing and managing time as it is about managing and containing matter. Safety is about prolonging the present of the GDF's ability to contain waste to mediate the much longer now of nuclear waste. The challenge for crafting containment is less the radioactivity of nuclear waste than the *slowness* of radioactive decay. The incommensurability between nuclear waste and humans and human-made things introduces epistemological challenges to GD. It is the incommensurability of nuclear and human times that impels me to reconsider GD future making as the making of contain-ability.

The notion of *contain-ability*, thus, directs attention towards the uncertainty and situatedness of future making, the temporality of disposal and the challenge of managing nuclear waste, a hyperobject that is distributed in time beyond human experience and knowledge. As an 'unrealised real present possibility', contain-ability poses difficult questions around future making and responsibility.

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[16] One could also interpret the accident in the WIPP as demonstrating unrealised (perhaps even unrealisability) of containment.

Disposal cultures have been delegated the responsibility for making safe distant futures, yet there is inevitable uncertainty about the outcomes and functioning of the GDF (in the long-term). This uncertainty does not absolve disposal culture and the implementing generations of responsibility. Accepting that responsibility for the future flows directly from actions in the present rather than knowledge of potential outcomes in the future (Adam and Groves, 2007), contain-ability underlines the necessity to carefully consider what kinds of futures societies are willing to set in motion in the present. Are today's nuclear nations willing to subject other beings, peoples, spaces and time to the potentially risky consequences of decision made in the present? What kinds of future risks or hazards are nuclear nations willing to shoulder? Contain-ability, in this sense, helps to raise questions about alternative futures.

Akin to the concept of sociotechnical experiments, the notion of contain-ability highligts the openness and uncertainty of future making through GD. By challenging the binaries between disposal and storage, waste and asset, contain-ability questions official imaginations of GD as an end point to nuclear waste management. In doing so, it highlights a space for the emergence of alternative unplanned futures. Thus, what I propose here that the most effective way to make safe futures through GD might be generosity towards openness and uncertainty, as discussed in Chapter 2, rather than an emphasis on closure and finality proliferated in official imaginations of GD.

7.4 For the future

In this thesis I have explored how the UK and Finnish disposal cultures seek to make safe distant futures through GD. Disposal cultures (Chapter 3) is a method I developed to bring the two GD projects into a conversation with each other and to avoid direct, unfruitful, comparison between them. On the other hand, disposal cultures are also an object of study. They emerge from and are shaped by the existing nuclear industries and waste inventories together with research, policy, industry and regulatory actors and practices. It is the emergent differences between disposal cultures that help to illuminate some of the challenges and concerns in the implementation of GD. Indeed, the 'smallness' or cohesion of the Finnish disposal culture appears to have fostered continuity and a more smoothly progressing GD project in contrast to the UK case. The

UK disposal culture has been shaped by a more eclectic collection of policies and actors over the years (Chapter 4), and the UK GD project has come to be characterised more by discontinuities and uncertainties.

In part these differences stem from historical care practices, that is, from the ways in which nuclear waste has been managed over time. In Finland, nuclear waste has been more solidly tied to direct disposal from the beginning of Finnish nuclear activities, whereas in the UK the management of nuclear waste has been dominated by shorter-term technopolitical considerations (e.g. weapons, fast breeder reactors), which have generated a more complex nuclear waste inventory. Yet, what both cases show is the close and precarious relationship between care practices and future making. The UK case amply evinces the consequences of past future imaginations and how future making can slip into future taking (Adam and Groves, 2007) when policies change, technologies fail and past decisions and visions come to dominate the courses of action in the present. Thus, the ways in which the UK, as well as Finland, plan to take care of its nuclear waste inventory emerges from their local sociotechnical realities (Mol, 2008), but they also demonstrate how care practices are not innocent, but involve prioritisation and choosing of sides (e.g. Puig de la Bellacasa, 2011, 2017; Haraway, 2016).

What the Finnish and UK cases highlight is the difficult dynamic between time and care. The UK's GD project continues to be captive to shorter-term considerations (plutonium, new build), while within the Finnish disposal culture some concerns have been voiced that care for the GD project itself has become prioritised over taking care of nuclear waste through GD, as the completion of Onkalo threatens to take precedence over long-term safety (Chapter 6). GD projects thus highlight the importance of the questions about care ('Who cares?' 'What for?' 'Why do 'we' care?', 'How to care?') put forward by Puig de la Bellacasa (2011). Considering the long-term futures at stake in nuclear waste management, and GD in particular, thinking through and with these questions is vital. As a hyperobject (Morton, 2013), nuclear waste expands into times and spaces beyond knowledge, and official imaginations of the permanence GD (as care) are problematic. While, in a sense, the UK and Finnish disposal cultures, themselves, struggle with the long timespan of GD, they still tout the permanence of GD. Yet, the very longevity of nuclear waste may require that conceptualisations and practices of care are open to change, rather than set in time. The recognition that nuclear waste will outlive the GDF is more in line with the notion of GD as a 'sociotechnical experiment' (Landström and Bergmans, 2015; Schröder, 2016) than it is with the official imaginations of permanence. The notion of 'sociotechnical experiment' is sensitive to the observation that future generations "have to cope with the consequences of our [present actions]" (Adam and Groves, 2007: 176) and to the uncertainty of future making in the present (Chapter 5). It highlights that care should be understood as a temporal and reversible practice in order to make safe distant futures through GD.

Yet the prioritisation of GD over other nuclear waste management alternatives and futures not only by the UK and Finnish disposal cultures, but also by the broader international nuclear waste community, has closed down public debate around the long-term management of nuclear waste and GD in particular. GD projects tend to be driven by technocratic logics that seek local acceptance to a disposal concept deemed safe by the international nuclear waste community. By highlighting the relational and negotiable aspects of safety and future making, this thesis has policy implications. In the first instance, it challenges the traditional 'social' explanations to the fortunes of GD projects as insufficient and simplistic, and further posits that these explanations need to be opened up to better conceptualise how the 'social' and the 'technical' are entangled in GD projects. Thus, by questioning the singularity of safety, the idea of the GDF as a 'readily implementatiable' and traditional explanations, this thesis makes the case for a more co-productionist approach (Jasanoff, 2004) to the GDF design and siting process. It does not argue that 'just everything goes', but rather that there is room to include potential host communities and other publics earlier and more broadly in the implementation process than has been done up to now.

Second, by underlining safety as the result of situated makings rather than a property of GD, this thesis makes the case for opening up debates on the long-term management of nuclear waste. It underscores how the making of safety and safe futures takes place through contrasting and relating GD to available alternatives, and through the mobilisation of available resources from the bedrock to waste to cultural imageries. In doing so this thesis invites and contributes to debates on GD, alternative waste management solutions and possible futures. While this thesis does not question the *potential* of GD to produce and deliver safe futures, it proposes that GD's ability to provide safe futures lies within the realm of the possible rather than in the realm of the probable, and since the workability of the GDF cannot be tested and verified in the present, it should be opened up for debate. Thus this thesis is in a position to broaden and inform discussions between waste management organisations, policy-makers and local communities in countries that are in the middle or are entering challenging phases of their GD projects – such as the UK that is just restarting the siting process or Sweden, where the regulator showed a green light to the construction of the GDF in January 2018 (WNN, 2018).

To conceptualise GD's possible ability to provide safe futures, I have introduced the notion of *contain-ability*. The notion of contain-ability challenges the divisions between disposal and storage, waste and asset on which technoscientific imaginations for the safety of GD rest. It also underlines the temporality, contingency and precariousness of containment, as such contain-ability has applicability in waste and discard studies and STS more broadly beyond the fairly narrow focus on GD. Emphasising containment, and closure, as something with a temporal aspect, something that can be gained but also lost, the notion of contain-ability can be utilised for instance in the study of controversies. It underlines the ability and potential to matters to resurface; how material and/or discursive containment can unbecome, and the precariousness of closure.

7.5 Summary

In this final chapter, I synthesised the main arguments I have made in this thesis and offered my contributions to the field of STS. I proposed that time – the discrepancy between human and nuclear times – is the biggest challenge disposal cultures face in the making of futures through GD. The incompatibility between nuclear and human times makes it impossible for GD cultures to know the futures they seek to protect and create, as nuclear time expands beyond the capacity of contemporary knowledge making practices to accurately predict and map the future.

I then contended that a significant difference between the UK and Finnish disposal cultures that emerges from this study is the way in which these cultures relate to nuclear waste. On one hand, the two disposal cultures have mobilised the extensively long lifespan of nuclear waste in diverging ways. Where the Finnish disposal culture calculated the earliest possible disposal date based on the lifespan of nuclear waste, thus using this lifespan as the foundation for a structured GD project, in the UK the same lifespan has been used to justify inaction and procrastination as no immediate need to address the issue was perceived. On the other hand, the materiality of nuclear waste inventories in the UK and Finland has informed the way the disposal cultures conceive the idea of GD as the 'end point' of nuclear waste management. In the UK, where nuclear waste is a form undisposable as such, waste needs treatment prior to disposal. What this means in practical terms is that waste categorisations are irreversible. Once waste has been treated, it cannot be separated from its wasteform. This results in a rigid reading of the 'finality' of disposal and might also contribute to delays in the implementation of GD, as the UK Government is unwilling to classify nuclear materials with potential future uses as waste. In contrast in Finland waste needs no treatment before disposal. This, together with the inclusion of retrievability in the disposal concept, allows the potential unmaking of waste at a later date. Retrievability in the Finnish reading ensures that waste has the potential to revert to an asset, and disposal to storage. Thus, the Finnish disposal culture emerges as more willing to embrace waste and disposal as temporal rather than final categories, although at the moment GD remains the sole policy aim for the long-term management of nuclear waste.

Thirdly, I argued that safety is made through *relational sociotechnical doings*. It is not a property of GD. I traced how safety is made through contrasting and relating the aboveground and the underground. The underground is constructed as safe *in relation to* the aboveground. Where the aboveground is considered as unpredictable, fickle and vulnerable to societal, environmental and climatic changes, the underground is posited as stable, predictable and less prone to disruptions. The assumed cyclicality or underground time is contrasted against the perceived linearity of aboveground time, as a measure of predictability. I further posited that not all underground spaces are considered equal. Rather, underground safety is constructed through available geological resources; with the strengths of the available geology highlighted against the perceived weakness of other potential geological environments.

Finally, I introduced the notion of contain-ability as a means to better discuss and conceptualise the temporality and contingency of GD future making. Contain-ability challenges the divisions between disposal and storage, waste and asset on which technoscientific imaginations for the safety of GD rest. It thus helps to further underline the situatedness of the making of safe futures through GD.

Appendix I – Participant Consent Form and Information Sheet

Participant consent form

Title of Research Project: **Disposal Cultures: Nuclear Waste Management Practice and Policy in Finland and the UK**

Name of Lead Researcher: Marika Hietala

Participant Identification Number for this project: Please initial

box

1. I confirm that I have read and understand the information sheet and I have had the opportunity to ask questions about the project. ☐
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question or questions, I am free to decline. ☐
3. I understand that my responses will be kept confidential.
   I give permission for other members of the research team to have access to my anonymised responses. I understand that my name will not be linked with the research materials, and I will not be identified or identifiable in the report or reports that result from the research unless I give my consent. ☐
4. I agree for the data collected from me to be used in future research ☐
5. I agree to take part in the above research project. ☐

________________________ ______________ __________________
Name of Participant Date Signature

________________________ ______________ __________________
Name of person taking consent Date Signature
(*if different from lead researcher*)

________________________ ______________ __________________
Lead Researcher Date Signature

Copies:

Once this has been signed by relevant parties the participant will receive a copy, to keep with the information sheet and any other written information provided. A copy of the signed and dated consent form will be placed in the project's secure storage.

INFORMATION SHEET for RESEARCH PARTICIPANTS

PROJECT TITLE

Disposal Cultures: Nuclear Waste Management Practice and Policy in Finland and the UK

INVITATION

You have been contacted because you are a member of a nuclear engineering group or are working in a related area (another scientific field, policy arena, industry etc.).

You are being invited to take part in a research project that is studying the innovation and implementation processes related to geological disposal in the UK and Finland. In particular, this study focuses on geological disposal as a socio-technical system.

Before you decide whether to take part in the research, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask me (Marika Hietala) if there is anything that is not clear or if you would like more information.

Thank you for reading this.

PURPOSE of the RESEARCH

To investigate and understand the scientific work that goes on in the design and implementation of geological disposal.

COMMITMENT

It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep has it contains my contact details. You will be able to withdraw from taking part in the research at any time by contacting me. If you decide not take part or wish to withdraw please, please ensure I have been informed.

WHAT TO EXPECT

I may visit your place of work and record (often written notes) some of the activities that take place there. I may also ask you to take part in recorded conversations or individual / group discussions about your research. My visits are intended to be informal occasions and I may ask to simply follow you around for a while as you do your everyday work. There will hopefully be little disturbance to you and your on-going activities. Although I will spend time with you as an individual, the research is not studying you as a person, rather just the kinds of things that go on in your work and what you feel about those and your area of work more generally.

BENEFITS

While there are no immediate benefits to people taking part in the project, it is hoped that this work will contribute an understanding of the technical and social complexity of implementing geological disposal, and may raise awareness among scientists and engineers about some of the factors impacting the way contemporary science is conducted and developed.

CONFIDENTIALITY

Any information that I collect will not be attributed to individuals without explicit consent. I will not identify any people, laboratories or institutions by name, but will allocate IDs or pseudonyms to identify these in any reports or papers I will write. On any rare occasions where it might be important to my analysis, I will seek express discussion and permission to name individuals in the writing that comes out of the field study.

INFORMATION

Any digital recordings (audio/photographic) made during this research will be used during analysis and may be used for illustration in conference presentations or lectures. No other use will be made of them without your written permission, and no one outside of myself or my supervisor will be allowed access to the original recordings. If being interviewed using digital audio, you will be asked to give explicit verbal consent to the interview.

RESULTS

My primary aim is to write up the analysis of the data as a doctoral thesis. Some of the anonymised data will likely be used for presentations and academic publications.

ETHICAL APPROVAL

The project has received ethical approval from the University of Sheffield, Department of Sociological Studies Ethics Committee and will follow professional guidelines laid down by the British Sociological Association.

CONTACT

If you have any questions about the work or about the conduct of the researchers, then please contact me, Marika Hietala:

Email : mthietala1@sheffield.ac.uk

Or my supervisor, Dr Molyneux-Hodgson : s.hodgson@sheffield.ac.uk

If you decide to take part in the research, please sign the Consent Form attached.

MANY THANKS

Appendix II – List of Participants and Interviews

Participants

Participant Code	***Participant Role***
UK	
Alex	PhD student – materials science
Arthur	RWM – research manager
Christopher	PhD student – materials science
Colin	CoRWM member
David	PhD student – materials science
Jodie	PhD student – materials science
John	Consultant – safety case
Kevin	Lab technician – materials science
Mark	Lab technician – materials science
Matt	University professor – nuclear materials
Nicholas	Industry representative
William	Former CoRWM member
Finland	
Aila	Posiva – research manager
Eero	VTT research manager
Elina	VTT researcher – corrosion
Ilkka	Posiva – retired advisor
Jukka	Consultant – biosphere
Johan	University professor – engineering
Lilli	Nuclear regulator
Marja	Civil servant – nuclear section
Markku	University professor – engineering
Matti	VTT researcher – copper
Rabbe	GTK Researcher
Samuli	PhD student – rock mechanics
Tapio	University professor – geology
Tom	PhD student – engineering
Ulla	University researcher – chemistry

Interviews

Participant Code	***Interview Date***	***Mode of Interaction***
UK		
Alex	17th July 2015	In person
Arthur	17th March 2015	In person
Christopher	3rd December 2014	In person
Colin	9th April 2015	In person
David	3rd December 2014	In person
Jodie	17th July 2015	In person
John	16th March 2015	In person
Kevin	18th May 2015	In person
Mark	21st May 2015	In person

Matt	25th June 2015	In person
Nicholas	28th May 2015	Telephone
William	30th January 2015	In person
Finland		
Aila	14th January 2016	In person
Eero	17th November 2015	In person
Elina	7th March 2016	In person
Ilkka	8th February 2016	In person
Johan	2nd February 2016	In person
Jukka	28th September 2015	In person
Lilli	8th March 2016	In person
Marja	21st October 2015	In person
Markku	10th September 2015	In person
Matti	7th March 2015	In person
Rabbe	22nd October 2015	In person
Samuli	9th December 2015	In person
Tapio	2nd March 2016	In person
Tom	21st September 2015	In person
Ulla	18th February 2016	In person

Appendix III – Example interview schedule

16 March 2015 Interview

So I have four broad themes I'd like to discuss today; your career, the UK's nuclear waste disposal eco-system, research in the UK and policy implementation, does that sound OK?

Career
You have made an extensive career in the field of nuclear waste disposal, could you give me a brief potted biography of your time in the field?

- So are those all the roles you've undertaken?
- Just to clarify, has your whole career been in consultancy?
- Going a bit further back on your personal time line, what did you study in university? Where did you study?
- How did you end up working on nuclear waste disposal?

Do you remember back to earlier days when perhaps people thought a GDF would be a reality by now?

- If not, can you speculate why the implementation of waste disposal seemed unproblematic at that time?
- What happened/went wrong?

NWM eco-system
Going back to your role as a consultant, what is it exactly that you do?

- Can you give concrete examples?

Who are the major players in the UK's nuclear waste disposal eco-system?

- What are the relationships between these players? How do they relate to each other?

Where do consulting bodies or companies fit into this eco-system?

You've worked across the board with bodies like the EA, CoRWM, RWM etc., does the work that you do and have done for these different bodies differ in some ways?

- Do they ask different types of questions? Or emphasise different things?

RWM is a central but also a fairly new actor in the implementation of geological disposal what kind of a role are they playing?

- What should they be doing? What is expected of them? Why?
- Are times under RWM different from earlier regimes, like Nirex?

Safety case
What is a safety case?

- What is it purpose? Can you explain that in layman terms?

What are the most significant remaining scientific knowledge gaps in relation to geological disposal?

- Is there a priority order? Should there be?

How far does everything have to be 'known' about a particular process or problem?
- What levels of uncertainty are allowed?
- Who decides the acceptable margin of error? Is it the RWM or the different research groups?

In terms of research activities, is waste disposal eco-system coordinated in some way?
- Is more coordination needed? Why? Why not?

Policy implementation

You have significant experience of nuclear waste disposal nationally and internationally, are there some aspects or factors of the UK's approach to nuclear waste disposal that are particular to the UK?

The UK is planning a co-located GDF, what are the main benefits of this arrangement?
- Does the co-location of wastes pose particular research problems and if so what kind?

Are there countries the UK has particular close relations with in terms of research and of GDF visions/missions?
- What can the UK or RWM learn from foreign experiences?

What are your hopes for the implementation of geological disposal in the UK under the new White Paper?
- What do you see as the biggest barriers to its implementation?

As a geologist, what is your view of the National Geological Screening?

What are the biggest remaining challenges overall in relation to GDFs around the world?

Finishing

Do you have any question you would like to ask me?

What questions did you expect to be asked?
- Was the interview what you were expecting?

Can you think of people it might be worth me chatting to?

Thank you!

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