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Preface on InSOTEC

InSOTEC is a three-year collaborative social sciences research project funded under the European Atomic Energy Community's 7th Framework Programme FP7/2007-2011, under grant agreement n°2699009.[1] The project aims to generate a better understanding of the complex interplay between the technical and the social in radioactive waste management (RWM) and, in particular, in the context of the design and implementation of geological disposal (GD).

In doing so, InSOTEC wants to move beyond the social and technical division by treating RWM and GD as 'socio-technical' challenges.

ON THE INTERTWINEMENT BETWEEN THE SOCIAL AND THE TECHNICAL

As of the 1980's, a new strand of social scientific research emerged, which considered the social world to be shaped or influenced just as much by the technology it uses, as that technology itself is shaped by its social environment (e.g. Bijker et al., 1987; Callon et al., 1986; Elliot, 1987; Latour, 1986; Law, 1986; MacKenzie and Wajcman, 1985). From a Science and Technology Studies (STS) perspective, actions and decisions take place within hybrid collectives, that is, combinations of what we usually call the social (human actors, relationships, norms, groups, values, etc.) and things deemed technical (technical equipment, measures, calculations, tools, texts, etc.) (Callon and Law, 1989: 78). When we look at the making and design of aircrafts, bicycles, ships, buildings, nuclear reactors, light bulbs, diesel motors, or bridges, what we see is that beyond what might look like mere technical questions lie assemblages of humans and non-humans, subjects and objects, the social and the technical. In this sense, "artifacts have politics" (Winner, 1986): artifacts embody political visions of society and, at the same time, they have consequences upon the ways in which humans relate to each other and to their environment. Consequently, when actors modify and translate their interests they simultaneously modify and translate the knowledge and technological artifacts they use, develop and believe in, as well as their identities as actors. This is a reason to talk about socio-technical combinations instead of technical aspects on the one side and social aspects on the other, or about a technical 'content' surrounded by a social 'context'. What goes on in an innovation process is mutual adaptation between many factors gathered together in one and the same process, where involved actors - whether engineers, politicians or engaged citizens - do not separate between what is usually defined as technical and social factors. On the contrary, they know that they have to include both technical and social aspects in order to be successful. For many technologies, the relationship between social and the technical indeed has become stable, relatively unambiguous and not open to fundamental controversy. Today it would be hard to imagine a world without cars, microwaves or the internet, while less than 150 years ago, bicycles were considered a controversial

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[1] InSOTEC partners are: University of Antwerp (Belgium), University of East Anglia (UK), OEKO Institute (Germany), Göteborg University (Sweden), CNRS – Ecole des Mines de Paris (France), MTA TK (Hungary), GMF (Spain), University of Tampere (Finland), University of Jyvaskylan (Finland), University of Ljubljana (Slovenia), Charles University (Czech Republic), Merience Strategic Thinking (Spain), University of Oslo (Norway).

technology and several different models competed for social approval (Pinch and Bijker, 1989). Conversely, technologies disappear (e.g. steam engines, cassette recorders, VCRs, or the Concorde airplane), and this for a host of different reasons. For geological disposal, although commonly presented by the expert community as the best available technology today to deal with the long-term management of high-level waste and spent nuclear fuel, such stability is clearly not present. In fact, deep geological disposal remains today in many respects a hypothesis, of which the functionality has not been empirically demonstrated for actual long-term safety. Furthermore, the question remains if it will ever be possible to 'demonstrate' long-term safety given the extreme long timescales involved.

ON SOCIO-TECHNICAL CHALLENGES FOR GEOLOGICAL DISPOSAL

Geological disposal is a particular technical concept to deal with the problem of radioactive waste; a technology that is considered by the expert community as the best available: *"The prevailing view of technical experts, as well as of many members of the general public that have been familiar with the work relating to geological disposal, is that geological disposal is a safe and technically achievable solution."* (NEA, 2008a: 14). In 2011, the European Council adopted a new Directive "Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste" [2], which takes this technical consensus as a basis: *"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"* (consideration (23) framing the Directive). As a consequence it urges Member States to develop and implement national programmes for the management of all spent fuel and radioactive waste under their jurisdiction, including disposal as the final stage in the management of radioactive materials (article 11 - §1). This suggests that today also a political consensus exists at the European level that GD is the technology of the future, where high level waste and spent fuel are concerned.

However, this does not mean that this technical concept is no longer controversial. Many of the general public, as well as many environmental groups and scientists from other disciplinary backgrounds, are still not convinced. The last Eurobarometer survey on attitudes towards radioactive waste for example showed that despite 43% of the Europeans polled thinking deep underground disposal to be the most appropriate solution for the long-term management of high-level radioactive waste, still more than 70% of all respondents did not believe that there actually is a safe way of getting rid of it (TNS, 2008: 23-24). This may or may not have to do with the fact that few people are familiar with the concept of GD and the potential attributed to it by the research done so far in that field, as the above quote from the NEA - RWMC statement suggests. Still doubt remains even among those more familiar with the work on GD. In a review of scientific papers on the subject, commissioned by Greenpeace, Wallace (2010) stresses the remaining uncertainties and gaps in

[2] Council Directive 2009/71/Euratom of 25 June 2009 establishing a Community framework for the nuclear safety of nuclear installations [OJ L 172, 02/07/2009, p. 18–22].

knowledge, for example on corrosion and chemical effects. While the RWM community acknowledges the existence of these uncertainties, they are not considered problematic. It is argued that they are treated in the so called 'safety cases'[3], focussing on the question of long-term safety (i.e. after closure of a GD facility), and thus taken into account. However, a safety case is a very technical concept, based on modelling, mathematical analyses and performance calculation. It is a complex given that is not widely known outside the RWM community, and controversy does remain concerning methodology, as critics such as Wallace (2010) have expressed concerns regarding the reliability of models predicting long-term repository safety.

What is also clear, is that the concept of GD has developed, and will continue to do so, not only because of evolutions in scientific knowledge, but also as a consequence of debates on how to integrate this technology into society. A clear example of this, is the introduction, by legal obligation, of the seemingly contradictory notion of retrievability into the concept of GD in Switzerland[4] and that of reversibility in France[5]. The adapted concept of GD that is being developed in these and other countries today (see for example the NEA's R&R project: NEA, 2011) still has to prove its capacity for resolving competing values (e.g. on control and controllability; or on leaving options for future generations versus not passing any (undue) burden on to them) with regard to the safe disposal of radioactive waste. But it does show that we need to think about GD (or more generally any technique to provide in the long-term management of high level waste or spent fuel) not as a technology designed by scientists and experts, but as a socio-technical concept of which the meaning and characteristics are negotiated and value laden.

InSOTEC METHODOLOGY AND STRUCTURE

InSOTEC focuses on situations and issues where the relationship between the technical and social components of RWM and GD in particular is still unstable, ambiguous and controversial, and where negotiations are taking place in terms of problem definitions and preferred solutions. Such negotiations can vary from relatively minor contestations, over mild commotion, to strong and open conflicts. Some concrete examples of socio-technical challenges are the question of siting and, as already suggested, of introducing the notion of reversibility and retrievability (R&R) or long-term repository monitoring into the concept of GD. This shows that the concept of GD develops over time, not only because of evolutions in scientific knowledge, but also as a consequence of debates on how to integrate this technology into society. Other examples of such development, are an evolution in many countries from the idea to build-operate-close to a more modular approach, and an evolution from out-of-sight, out-of-mind approach to one of continuous oversight and active memory keeping after closure.

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[3] A safety case in the context of geological disposal can be described as "a synthesis of evidence, analyses and arguments to quantify and substantiate that a repository will be safe after closure and beyond the time when active control of the facility can be relied upon" (NEA, 2008b).
[4] Kernergiegesetz, vom 21. März 2003 (*Nuclear Energy Act* - 21 March 2003)
[5] Loi n°2006-739 du 28 juin 2006 de programme relative à la gestion durable de matières et déchets radioactifs (*Radioactive Materials and Waste Planing Act* - 28 June 2006). On the notion of reversibility In France, see also Aparicio (2010).

Whether in a pre-siting, siting or more advanced stage of the implementation of GD, implementers all over the world are looking for ways of addressing stakeholder concerns regarding how to integrate societal 'boundary conditions' (including concerns about safety, but also for example political and economic constraints) with the environmental, technical and regulatory 'boundary conditions' for disposal facility design. Such integration and attuning is needed to determine the social feasibility of technology, at a certain point in time. It is also needed to sound the technical viability of specific socio-political expectations and demands (think for example about the issue of R&R). InSOTEC aims to provide a valuable contribution to this challenge by developing a fine-grained understanding of how the technical and the social influence, shape and build upon each other in the case of RWM and the design and implementation of GD. How are socio-technical combinations in this field translated and materialized into the solutions finally adopted? With what kinds of tools and instruments are they being integrated? A better understanding of RWM in terms of socio-technical challenges and combinations allows the concept of GD to be seen not merely as a technical artefact to be introduced in a not necessarily receptive social environment, but as part of that social environment and therefore partially shaping it and being partially shaped by it. GD is in this respect viewed as a possible means to attain a long-term management of radioactive waste, rather than as a goal in itself. The socio-technical challenges for implementing GD will therefore be looked at within the broader context of how RWM strategies are defined (by 'technical' and 'social' stakeholders) and how GD fits into these strategies.

The work in the InSOTEC project is structured into seven work packages (WPs). Three of those are supportive WPs dedicated to communication and dissemination activity, the organisation of seminars, and project management. The <u>four research oriented WPs</u> are organised as follows:

WP1 provides a review of national and international RWM focusing on the correlation of socio-political and techno-scientific challenges and whether or not they are acknowledged and dealt with as such.

WP2 consists of an assessment of mechanisms regarding the interaction of social and technical challenges through a number of case studies. These are: siting; technology transfer and transfer of socio-technical innovations; the issue of R&R; and the demonstration of safety.

WP3 looks at arenas where socio-technical combinations on RWM are formed through the co-production of knowledge between different actors. For this reason, networks or spaces are explored where people and organisations from various backgrounds interact with each other and create knowledge through a process of dialogue. A particular case study is the Implementing Geological Disposal Technology Platform (IGD-TP)[6].

[6] This technology platform was established in 2009 on the initiative of a number of European waste management agencies. European Technology Platforms (ETP) are a specific tool supported by the European Commission (EC) to bring together R&D-relevant stakeholders with various backgrounds, led by industry, to set a strategic research agenda and to develop a long-term R&D strategy and action plans in technological areas of interest to Europe (http://cordis.europa.eu/technology-platforms/home_en).

WP4 links the research activity to the practice of RWM and GD by offering concluding reflections and recommendations.

Throughout the project, seminars and other regular contacts are organised to stimulate interaction, exchange and learning between different concerned actors. Also for that purpose, a Stakeholder Reflection Group was installed, an advisory committee composed of nine individuals representing different groups interested in the subject (social scientists, implementers, local communities involved in RWM issues, national oversight bodies, the IGD-TP and the NEA). It is set up to ensure that different perspectives from potential end users are taken into account, that interaction between them is stimulated, and that the results are useful to the 'practitioners' in the field.

InSOTEC AIMS

With this project, the InSOTEC partners hope to create greater awareness among the technical community of the social implications of their work, as well as of the underlying social assumptions that directly and indirectly colour the solutions they are developing. At the same time the partners hope the project will also provide other parties concerned (such as political decision makers or involved communities) with a better insight into the origins of certain technical concepts, which may help them to be better equipped when dealing with these issues in their own context.

Complementary to providing better theoretical insight in the complexities of RWM, and GD in particular, by describing them as socio-technical challenges, InSOTEC aims to provide concrete suggestions on how to address the actual socio-technical challenges identified within national and international contexts. We expect to offer insights (e.g. with regard to technology transfer and transfer of socio-technical innovations, the issue of reversibility, the inclusion of social aspects in the safety case model, …) to scientists and technical experts that could help them to communicate in a two way process about their work and to engage with stakeholders on technical and safety issues. With regard to the IGD-TP, InSOTEC will also investigate whether and how stakeholders representing different parts of concerned society with different backgrounds could be linked to the platform on a structured basis. In addition, advice will be provided on how to set priorities for a multidisciplinary research agenda which incorporates social sciences and which will address socio-technical challenges in a coherent and integrated way.

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Synthesis Report on Socio-Technical Challenges for GD

1 Introduction

This report aims to clarify the dynamics of socio-technical challenges in the implementation of geological disposal (GD) for High Level Waste (HLW) and Spent Nuclear Fuel (SNF). Drawing on the 14 country reports produced within InSOTEC's WP1 the synthesis focuses on socio-technical challenges that appear across national contexts. The synthesis report elucidates issues made visible through bringing together the analyses of different national contexts. The analyses conducted in the 14 country reports will not be repeated in the synthesis, but examples will be drawn from them to illustrate specific issues. The country reports are attached as appendices to the electronic version of this report, made available on the InSOTEC website (www.insotec.eu) in order to provide access to the detailed studies of national socio-technical challenges.

In this synthesis report the main interest is in socio-technical challenges to geological disposal of HLW and SNF, with only occasional mention of other waste categories. This is a narrower focus than in the country reports, of which some provide detailed discussions of Low Level Waste (LLW) and Intermediate Level Waste (ILW) which are also subject to geological disposal. In some countries there is currently more activity going on with regard to the disposal of LLW and ILW (destined for either geological or surface disposal), with HLW/SNF repository development put on hold. However, in several of the countries studied there is what can be called 'temporary discursive closure' with respect to LLW and ILW, meaning that the actors involved consider the issue to have been solved, or at least, not as posing challenges that require immediate address. This is nowhere the case for geological disposal of HLW/SNF: there is no discursive or practical closure of the issue, challenges are multiple and national policies continuously evolving. Hence, we focus on this process. When relevant we make reference to management of other waste categories, but we do not attempt a systematic comparison of LLW or ILW disposal.

The discussion in this report draws on approaches developed in Science and Technology Studies (STS), particularly perspectives emphasising the non-deterministic character of socio-technical processes and the unpredictability of policy decisions (Latour, 2004; Sarewitz, 2004). STS scholars insist on studying processes in a manner sensitive to variations in circumstances and to approach science and technology as shaped in specific social contexts. A basic assumption is that the outcome of a socio-technical process does not follow linearly from the technical knowledge, or from the social decisions made, but that unexpected effects emerge from social negotiations and material engagements, specific to time and place and have to be considered in the analysis. This approach differs from the rational decision making perspective which assumes that initial knowledge and formal decisions, determine process outcomes. The latter view is popular among both scientists and policy makers, as it emphasises the role of technical expertise in relation to public concerns. This report is also underpinned by an anti-essentialist understanding of actors and objects as getting their identities and characteristics by playing specific parts in processes in which they relate to others in specific ways. This view, critical to the notions of socio-technical challenges, was formulated in opposition to philosophical and scientific views of things and humans as having intrinsic identities that cause them to behave in specific ways in relation to others. These assumptions, about complex interactions among humans and things in the processes that change technology and society, set STS and this report, apart from social science perspectives that approach technology as external to social relationships and human actors as fixed entities with measurable opinions and stable values.

Applying an STS perspective to the 14 InSOTEC country reports makes four socio-technical challenges stand out as significant on the transnational level, at the present moment and with the potential to change the socio-technical combinations from which they have emerged. We begin with a brief overview of these.

A brief overview of four significant socio-technical challenges

The socio-technical challenge of **safety** is the original and primary issue for geological disposal of HLW/SNF. Safe disposal of HLW/SNF became an issue of interest to the scientific community early on in the development of nuclear energy as the radiation hazard of the wastes generated in nuclear power production was known by scientists at the time of inception of national energy programmes, before any waste had been created. Already in 1957 the US National Academy of Science identified deep geological disposal as the safest way to dispose of the waste that would remain hazardous to human health and the environment for many thousands of years (NAS, 1957). This scientific study set the terms for subsequent research and policy for safe disposal of HLW/SNF. In the decades following many countries developed research programmes investigating the options for geological disposal and policies to implement technical programmes. Although nearly all countries with HLW/SNF seem to have settled, explicitly by formal decision making, or implicitly by default, on geological disposal as the final solution for this hazardous material, there are interesting variations between the ways in which the 14 countries studied in this project have organised their programmes. To illuminate the ways in which national contexts differ, we present the countries in Table 1, comparing the ways in which they pursue geological disposal of HLW/SNF with respect to eight different aspects.

Despite early settlement on geological disposal as a technically feasible choice and a seemingly universal commitment to implementation having been established decades ago, no HLW/SNF repository has yet been realised, even if, in many countries legal frameworks and/or national policies have been adopted to this effect. This is partly a consequence of repository **siting** having developed into a major socio-technical challenge, as local publics and political opponents in many countries have contested the implementation of government decision-making. Some national programmes never even went so far, deterred by the reactions observed elsewhere. Again different ways of addressing this socio-technical challenge have been developed in the 14 countries. In some cases new socio-technical combinations in the form of voluntaristic siting procedures have been invented, which appear to be moving the implementation process forward. Some countries meanwhile leave the waste on site, others have opted for centralised interim storage while the siting procedure is addressed. Some countries seem to be able to negotiate their way forward without explicitly reinventing their policies. Others have deliberately postponed implementation of geological disposal, by introducing prolonged interim storage as an intermediary management option, and in a few countries processes seem to have stalled. To provide an overview of national pathways toward the implementation of HLW/SNF geological disposal, evolving from choices made at different times, we visualise the diversity of routes developed in the form of a map (figure 1).

After discussing the socio-technical challenge of siting we turn to **reversibility/retrievability**, another socio-technical challenge attracting attention in the technical community, as well as among policy makers and the public. While becoming more concrete in several countries, the concept of geological disposal for HLW/SNF has itself been subject to modifications. The simplified principle to 'build-operate-close' has evolved over the years to involve a more complicated interplay of the different phases throughout different stages of the facility lifetime. One discussion concerns the possibility of reversing the disposal process and/or retrieve the waste. In some countries reversibility/retrievability is required by law, which means that geological disposal concepts have to be developed in ways that maintain the safety while providing access to the waste in some form, at some point in time. In relation to the discussion of reversibility/retrievability among implementers and regulators we noticed the importance of international standards and experience sharing. The strong focus on international collaboration among the research and implementer communities directed our attention to transnational communication networks. The InSOTEC project includes a study of knowledge networks, such as the IGD-TP (Implementing Geological Disposal - Technological Platform) at EU level. In this synthesis report we also take the opportunity to trace less formal connections. Trying out a novel web mapping tool, devised to trace connections between actors, we explored the virtual links of implementer and regulators. Although very tentative this map of virtual connections prompts reflection on relationships between actors and issues in geological disposal (figure 2).

The final socio-technical challenge discussed in this report, **managing the long-term**, is not yet perceived as a pressing issue among most of the actors involved in implementing HLW/SNF geological disposal nationally. One issue discussed – preserving social memory – shows potential to force a radical reconfiguration of the boundary between the technical and the social. The issue as formulated by the involved actors is daunting: how to mark a site where this extremely hazardous waste is buried so that humans in the very distant future will understand the danger? The timeframe involved is longer than the history of human culture: a repository site will be hazardous for hundreds of thousands of years. Discussions of this challenge have so far come up with ideas that would lead to very different socio-technical combinations. However, from the analytical perspective assumed in this study we critique some implicit assumptions of the socio-technical imaginaries signalled in the discussions on long-term memory. Most intriguing we find a lack of attention to the somewhat shorter, but still long-term governance of the physical site within a local host community. There seems to be a residual notion of geographical distance of a repository from human habitation, originating in the initial conception of geological disposal. This idea has been superseded by the reconfiguration of relationships between disposal facility and society, from the outset in voluntaristic siting regimes and by local demands placed on the more traditional siting programmes. The introduction of local host communities changes the geographies of HLW/SNF disposal. Furthermore, the estimated operational lifetime of a facility seems to be extending in many cases, from a few decades to at least a century. The theoretical model of 'reversed mining' proved to be somewhat less self-evident to put into practice and even the strongest believers in geological disposal today seem to have come to realize that the strived for status of passive safety will not be obtained instantly; hence, the end of operations of a disposal facility will be just as much a social and political decision, as it will be a technical one.

In the following we begin with explicating the notion of socio-technical challenge. Having defined the notion, we then discuss the four socio-technical challenges outlined above in greater detail.

2 Notes on the source concept 'socio-technical'

The concept of socio-technical challenges is a foundation for the InSOTEC project, but it is not singular or fixed. This is important in light of the philosophical anti-essentialism that cautions against the belief of fixed meanings of language and with the potential of the concept to bring new insights. In the process of working out what the notion of socio-technical challenge can contribute to the understanding of a particular empirical phenomenon, we learn both about its semantic capacity and about the world we try to capture. The following discussion does not aim to constrain the variations in meanings of the concept, but to arrive at a definition that will further the purpose of this particular report. In order to achieve such a temporary stabilisation we first present a brief genealogy of the notion and thereafter clarify its use in the present analysis.

Starting with the term 'socio-technical' we find one InSOTEC project presentation prepared for a conference identifying it as 'situations and issues where 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). This definition follows the path laid down by the predecessor project: CARL, a social science endeavour aiming to bring together the social worlds involved in radioactive waste management.[7] Running from 2005 to 2007 the CARL project studied radioactive waste management in four countries and illuminated six themes in national and international contexts ('CARL', 2005). One assumption underpinning the research was that:

> social and technical factors are always inseparable. To manage radioactive waste is a technical task but also a political task. We never find 'pure' technical or 'pure' social factors. Of course it is possible to find people called technical experts, as well as politicians and

[7] The acronym CARL unfolds as: 'Citizen-stakeholders (C), Agencies responsible for radioactive waste management (A), social science Research organizations (R) and Licensing and regulatory authorities (L)' ('CARL', 2005).

> citizens. But this does not mean that the former know nothing about social aspects or that the two latter groups do not possess vital knowledge. Instead of asking about the social factors we should ask about 'socio-technical combinations'. (Bergmans et al, 2008, 42)

The 'socio-technical combinations' discussed in the CARL project were discerned in the empirical material and understood as manifesting in two different attitudes: one emphasising separation of the technical from the social, acting as if there was no connection between the two. The other type accepted the integration of the two and understood social order and technical artefacts as coproduced in the interplay between technical and social. As was concluded in an InSOTEC review of international research programmes, other 'governance' projects dealing with radioactive waste management, over the last decade, have also addressed the interplay between the social and the technical, albeit often in a less explicit way, and with a strong focus on the social, as this had up until the late 1990s not been given the same attention as the technical. Socio-political aspects (whether political preferences, public concerns, social values, national traditions, assumptions about future generations, financial aspects, decision making processes and so on) have tended to be presented as an 'add on' to 'techno-scientific' aspects (e.g. the kind of waste stored, the geological characteristics of the disposal site, the physical properties of storage containers, measurement tools), while at the same time it is acknowledged that the social and the technical are not that easily separable (Bergmans & Schröder (eds), 2012). Putting the focus on the entangled relationship between the two, CARL and InSOTEC can be understood to form a lineage of STS research on radioactive waste management and as bringing the concept of 'socio-technical' to this field.

Taking a step further back into the past we find that the notion of 'socio-technical' has been widely used in STS and with this being a conceptually and methodologically diverse field we can identify a multitude of uses defining situated meanings. The two uses closest related to CARL and InSOTEC are found in the study of technology as complex systems and in the work investigating the generation of hybrids to stabilise particular realities.

The notion of large technological systems was developed by historian Thomas Hughes in research on the electrification of the Western world (Hughes, 1983). He found that technical innovation was intrinsically linked to social actors and activities in the transformation of an individual invention into a widely used technology that changes society. Technological systems were networked with social, political, economic and cultural components and human reality was organised by such socio-technical systems. While Hughes, the historian, did not elaborate the notion of socio-technical, the sociologists he collaborated with did so in great detail, as they brought the concept into the STS limelight in the early 1990s (Bijker, Hughes and Pinch, 1987). This sociology of technology emphasised the need to understand technical processes as always involving social activities and aspects. Simultaneously, a more ontological reference for the notion was developed in the critique of the separation of the social and the technical that reached the international STS scene in Bruno Latour's article on sleeping policemen and door closers (1992). Latour argued that the sociological problem of whether agency or structure explained social order was wrongly conceived. It was actually a consequence of sociology's failure to account for the work technical artefacts do in society. In actuality, not only do technical processes involve social activities but the social, as such, is also technical and the technical embodies the social. The two were actually one. To separate them was an intellectual error introduced as modernity required ontological certainties. Latour's article had a major impact on the social study of technology, provoking a range of responses, both positive and negative and the implications of the claims put forth are still being worked through. However, while the notion socio-technical may have entered STS in the 1990s, it was already established in other fields of social research. In a discussion of the use of the term in innovation studies and environmental policy literature, the Finnish country report traces its origins to the sociology of work, most importantly research at the Tavistock Institute (Trist, 1981). In this field it was used to capture the interconnectedness of technical communities of practice, experts and institutions with the social order in which they operated.

This brief genealogy of the concept aids the clarification of what is new and different about the articulation of the socio-technical in the project discussed in the present report. Whilst the notion has a long history, the CARL project brought it to the issue of geological disposal of radioactive waste, inventing the notion of 'socio-technical combination'. The InSOTEC project takes a step further in adding 'challenges', which brings more intrigue. In the OED (Oxford English Dictionary) 'challenge' figures both as a noun and a verb, of the many meanings listed, the two most relevant for the present purpose are: 'a difficult or demanding task' and 'to claim attention' (OED, 1989). 'Socio-technical challenges' can, thus, be understood as difficulties demanding attention of a type that transcends the established conventions separating the social from the technical. Complementing 'combination', which captures the ways in which elements are linked together, 'challenge' adds a temporal dimension, because the subject matter is always a process. Socio-technical challenges arise as actors try to bring about a desired reality, in this case deep geological disposal of HLW/SNF, and in overcoming them new socio-technical combinations emerge.

3 Four transnational socio-technical challenges to implementing GD

The InSOTEC country reports identify a wide range of challenges facing national geological disposal programmes, not all of them can be classified as socio-technical according to the above definition. One example is financial strain. Unless funding shortcomings can be seen to affect the social organisation, the technical concept or the boundary between them, they do not qualify as socio-technical challenges in the sense adopted for the purpose of the present analysis. It is quite likely that financial challenges will become more acute if construction of repositories goes ahead and then they are very likely to impact on both technical and social aspects and their relationship, but this is not yet the case. There are also challenges identified in the country reports that may be understood as socio-technical, but context specific, in the sense of emerging from the particular socio-technical combinations stabilised in one country. The siting of interim storage facilities is one example. Although clearly a socio-technical challenge, this is not a transnationally unstable issue. The socio-technical combinations resulting from this in one country today will not be of major significance for most other countries because this kind of process has already been completed elsewhere, producing 'temporary discursive closure' in which the issue is no longer debated or subject to active policy innovation, but treated as solved. Although both kinds of challenges are important issues, this synthesis report is more interested in socio-technical challenges that have not yet been addressed in a manner that has made them recede from the spotlight in any of the studied countries. We are also interested in socio-technical challenges likely to arise if implementation moves forward as expected. We will address incipient issues, discussed among actors, not necessarily subject to national policy or public debate, but discernible as potentially able to prompt re-drawing of the boundary between the social and the technical, to become socio-technical challenges. This definition allows us to identify four socio-technical challenges for closer scrutiny in this report labelled for simplicity as: safety; siting; reversibility/retrievability and managing the long-term.

3.1 Safety

We understand safety to be the primary socio-technical challenge for HLW/SNF disposal and historically, the first to be addressed in national policies. Considering the evolution of national strategies over time, it is clear that the safe disposal of radioactive waste has been the driver for both technical and social innovation and that this challenge has caused reconfiguration of the boundary between the social and the technical. Safety has played this role in relation to all categories of waste. The country reports show how the safe disposal of LLW and ILW waste has been achieved in processes reconfiguring the relationships between actors and elements identified with either the social or the technical domain. One example is the surface disposal of 'category A' waste in Belgium, where some challenges were overcome by the invention of partnerships in which local communities and implementers could be brought together. In some countries LLW and ILW are disposed of in ways regarded as routine and considered safe. In one case, the USA, trans-uranic (TRU) military waste is disposed of in WIPP (Waste Isolation Pilot Plant), a geological repository. The examples from the country reports show that disposal of some categories of radioactive waste has been implemented in ways regarded as safe and effective, nationally. However, as mentioned in the introduction, the safe disposal of HLW/SNF remains unsolved everywhere and processes aiming to achieve this can be expected to reconfigure the boundaries between the social and technical currently in place.

The predominantly favoured solution to the general challenge of safe HLW/SNF long-term management is geological disposal. A pivotal 1957 report by the US National Academy of Sciences, produced on request of the US Atomic Energy Commission, *judged* geological disposal to be the safest method for disposal of high level wastes in *advance of research* and in the *absence of essential data* (NAS, 1957). NAS's appeal for further research on the subject prompted numerous research programmes which affirmed the 1957 judgment as far as possible. In the 1970s geological disposal emerged as the preferred policy solution, and many national programmes for its implementation followed. From the outset geological disposal was constructed as a technical solution, removing the hazardous material from unreliable societies and entrusting it to the reliable safe bedrock, in Latour's (1992) terms delegating safety to nature and technology. In this first stage governments were expected to implement this solution by constructing repositories where scientists identified the geological conditions considered most favourable, that is to say, asking for a minimum of engineering in support of safety functions. The initial socio-technical combination of geological disposal intended to solve the challenge of safety was based on separation; not only of the waste from human society, but also of the technical from the social. This approach to the challenge of safety did not work. The country reports detail the failures of such technocratic, top-down programmes, at different points in time, in different societal circumstances. One reason for the failures was widespread public opposition, on national and local levels. Trying to force geological repositories onto local communities was not a viable way to create safe long-term management of HLW/SNF. However, it did eventually force an understanding of the issue to be in need of not only scientific/technical knowledge, but also political and social negotiation. As the country reports show, a number of countries have rethought their strategies and created policies that thoroughly consider decision making and management procedures, making geological disposal socially acceptable as well as technically safe. Although the social and technical processes are not always clearly linked in the national policies, analytically they qualify as new socio-technical combinations and they emphasise integration of the social and the technical.

However, that the implementation of HLW/SNF geological disposal is moving ahead in some countries does not exhaust the issue of safety. By definition safety will remain a socio-technical challenge for HLW/SNF disposal until the waste is no longer hazardous, long into the future. Hence, safety will have to be continuously addressed in a number of different ways, most of them probably not yet invented, but unfolding if/when geological repositories are constructed and becoming operational. In the process of creating geological disposal safety will become many different issues in need of different types of actions. Currently, a widely adopted model for the social organisation of safety in the national programmes for geological disposal is to assign one body as implementer and another as regulator. Although the two can originate in the same government department, their purposes differ in that the regulator is focussed on making sure that the implementer follows all safety regulations and procedures when developing plans for repositories. In some countries the regulators' reviews of the implementer's work inform the decision making bodies; in others the regulator is also the licensing authority. In many cases the relationship of implementer and regulator revolves around a 'safety case'.

In many structural engineering projects (e.g. for military systems, the off shore oil industry, rail transport and the nuclear industry) explicit safety cases are legal requirements. Discussing methods to develop safety cases for construction projects, Bishop and Bloomfield (1998) define a safety case as '[A] documented body of evidence that provides a convincing and valid argument that a system is adequately safe for a given application in a given environment' (Bishop and Bloomfield 1998: 2). A safety case in the context of geological disposal typically refers to the post-closure phase (thus focussing on the question of long-term safety) and is described as 'a synthesis of evidence, analyses and arguments to quantify and substantiate that a repository will be safe after closure and beyond the time when active control of the facility can be relied upon' (NEA, 2008). While all countries studied are committed to the production of safety cases, the timing of these procedures differs, which has implications for their role. In some countries, safety cases feature already at the beginning of the siting process. This is, for example, the case in the UK, where the implementer is developing a generic safety case that will be the starting point in any specific locality. Regulatory agencies have already begun to review this generic safety case, commenting on necessary improvements and potential host communities have taken an interest in it as well. Another example, the Czech Republic, is different as the implementer RAWRA has decided not to develop the safety case until a site has been selected. The STS perspective adopted in this report encourages an understanding of the safety case as a boundary object, connecting different actors and facilitating the coordination of their actions. From the countries in which work on the safety case has begun, we also learn that the suite of documents will be subject to continuing updates, as new information comes to light through research, or when the implementation process moves forward. It is thus likely that the implementation of HLW/SNF geological disposal will change the idea of what a safety case can do in long-term construction processes. The country reports indicate that the safety cases will become much more specific and detailed if and when the location of repositories have become clear, even though they address future events. At such times, the safety case will also be a way to demonstrate the safety of geological disposal to concerned publics, in addition to being a boundary object connecting implementer and regulator. In the countries where local communities have volunteered to learn more about what it would entail to host a facility, we can see how the development of the safety case brings local publics into the process. For example, in the UK the safety case is an object that prompts interaction of implementer, regulator and local residents even in its current, generic form.

Safety will be an on-going concern that intersects with other socio-technical challenges, such as siting. However, it is also sensitive to other issues, which are not socio-technical challenges as defined in the present analysis, for example funding and the stability of political institutions. It is possible to imagine that the funding difficulties identified as looming on the horizon of the Swedish implementation programme could eventually impact on aspects of relevance for the approach to safety. It is also possible to envision consequences for the issue of safety in the Czech Republic if government institutions undergo radical change and regulatory responsibilities are not effectively carried out. These random examples are relevant for all countries and show that whatever happens, safety will remain the major socio-technical challenge, until the waste no longer poses a threat to human health and the environment. We must not forget that at present deep geological disposal remains a hypothetical solution to the socio-technical challenge of safe HLW/SNF disposal. It has not yet been implemented anywhere and when/if it is realised it will be very long before anybody will know if it works as expected. In fact, no one in this or the next few generations will ever know, which makes the case of HLW/SNF disposal such a specific challenge.

An interesting fact in relation to safety is that some countries have put their geological disposal plans on hold for what is presented as technical reasons, taking into account that plans could change if a better technical solution would be invented. Most countries are forging ahead with implementation programmes, but in some the process has stalled for a variety of reasons, not always explicitly decided upon. The hold ups again create intriguing situations with regard to safety as, on the one hand, the established objective is deep geological disposal, but on the other hand, no HLW/SNF waste is or has been placed in geological repositories. Still, all countries insist that their waste is currently kept safe. This contradiction is discursively solved through the introduction of different temporalities. Geological disposal is the safe long-term solution, but safety can be guaranteed in the short-term above ground. This is an argument that could potentially be used to suspend the implementation of geological disposal for hundreds of years, in effect bringing national programmes to a halt. For example, in the Netherlands centralised interim storage is planned to last for at least 100 years, in other countries different time-spans are in place. To provide an overview of national diversity in implementing HLW/SNF geological disposal to permanently solve the socio-technical challenge of safety we compare the 14 countries studied in a table with eight columns.

Country comparison *(Table 1)*

The **first column** in the table captures **the physical matter of concern** as articulated in national contexts. This may appear redundant since we have already identified the focus of this report as HLW/SNF. The IAEA provides an exhaustive classification of radioactive waste, defining the appropriate method of disposal for each category (IAEA, 2009). A graphic representation shows that deep geological disposal is the solution for High Level Waste (HLW) and Intermediate Level Waste (ILW) (IAEA, 2009: 16). Low Level Waste (LLW) and Very Low Level Waste (VLLW) can be disposed of in (near) surface facilities, the latter in standard landfill with other non-radioactive waste. The IAEA graphic scheme linking waste activity to disposal methods does not capture the issue of waste decay rate, the half-life, which is represented in a different figure (IAEA, 2009: 7). The choice not to represent both dimensions of the radioactive hazard together with disposal methods indicates the complexity of the issue and the variability in solutions. Disposal needs and strategies vary from country to country. In many countries LLSLW (Low Level Short Lived Waste) is disposed of in ways not considered controversial at this moment in time. In some countries there are public disagreements about long-lived LLW and/or ILW. Some countries have created facilities dedicated to ILW disposal. For example, the Czech Republic has four repositories for low and intermediate level waste. One is historical, in operation from 1959 to 1965. The remaining three are dedicated to different types of waste: 'Brarstvi for waste containing natural radionuclides only; Richard for institutional waste and the third one in Dukovany is used for waste generated in running two nuclear power plants' (Svacina & Konopasek, 2012: 4). In contrast, some countries have decided to dispose of ILW in the same geological repositories as HLW. Waste definitions do not only differ between countries, but also within countries over time, particularly with regard to SNF which can be classified as waste (e.g. USA) or as a resource if reprocessing is an option (e.g. France) or with classification remaining undecided (e.g. Belgium). The classification and treatment of SNF also affects the composition of HLW. In countries reprocessing spent fuel, HLW comprise reprocessing waste. Decisions about what is considered waste in need of disposal impact on the amount, which has implications for the size of a geological disposal facility and/or for the characteristics and capacities of interim storage facilities.

The issue of waste categorisation and the respective disposal strategies in the 14 countries is too complex to exhaustively represent in a table. The table focuses on HLW/SNF management in each country, providing only a glimpse of complex realities of varied and fluctuating definitions of the physical matter in question. The first column in the table captures the waste classified as HLW or SNF and intended for deep geological disposal each country accounts for at the time of writing. In some cases inventories have not been made available to the public, hence knowledge is limited. However, many countries compile regular inventory reports to inform stakeholders and the general public about the issue. Overall we can see that national inventories do not adhere to any proposed equivalence of measurement and that there is wide variation in the amount of waste between countries. Some countries also declare where the waste is currently stored and in which type of storage. There is variation with regard to who is storing it, in some countries the nuclear power plants generating the waste are responsible for it being kept safe, in others centralised specialist organisations have been created.

The **second column** truncates **the disposal concepts** adopted in each country. Here we again find variety, starting with the generality or specificity of geologies. Some countries only speak in general terms about geological disposal as such, while others have decided which kind of geology to work with whether or not a site has been identified. Further, some concepts are presented as predominantly technical, such as KBS3 in Finland and Sweden, while others explicitly encompass social aspects, e.g. the Canadian APM. Some concepts provide for centralised interim storage while siting is being addressed. All concepts connect technical and social dimensions, meaning that they are socio-technical combinations, albeit with different degrees of separation or integration.

In the **third column** we look at whether a country has a **dedicated HLW/SNF policy and/or legislative framework** currently in operation. Each of the countries has gone through many policy and legal changes over time, as detailed in the country reports. The table captures the frameworks organising the present activities undertaken in order to further the goal of HLW/SNF geological disposal. In the column we find the year/years in which the framework currently in place in each country was/were adopted. This demonstrates that in some countries, e.g. Finland, there is long-term legal and policy continuity, while other countries, like Canada, have recently started anew. Some country reports explain how policy discontinuities have resulted from public opposition to previously adopted plans. A few countries are at this point in time without any accepted legal framework for HLW/SNF management, due to different events occurring nationally. In the USA, for example, the collapse of the Yucca Mountain programme has left a legal and policy vacuum.

The **fourth column** characterises the **implementing organisation** along two dimensions. First, we distinguish whether the implementer is a government/state agency or a company. In light of a general political tendency of decreasing the direct role of the state in providing goods and services in all Western countries, it is no surprise to find that many implementers are organised as companies, distancing them from the political administration. However, given the national importance and sensitivity of the issue, the state appears not to be willing to relinquish all control. Hence the second distinction between public, private or hybrid company ownership. We find that the vast majority of implementing companies are public or hybrid. From the country reports we learn that only Finland has opted for private ownership, currently there are two companies involved with the implementation of geological disposal of HLW/SNF; the long established Posiva and the newly created Fennovoima. In some cases the establishment of a new policy has led to the creation of a new implementing body. This has been the case in, for example, Canada where the NWMO was created in 2002 to undertake a study of what would be the best way for Canada to manage SNF. When the NWMO's proposal for APM (Adaptive Phased Management) was adopted by the government, as national policy, the organisation was reconfigured into the implementing body. In contrast the Swedish SKB, a company with hybrid ownership, has been the implementing body of the evolving policy initiatives for over three decades.

The **fifth column** points to the ways in which different countries **involve (or plan to involve) civil society (i.e. concerned publics)** in the implementation of geological disposal. From the country reports we surmise that the Aarhus convention is an important point of reference with regard to the engagement of civil society. By mandating transparency of decision making, it demands that implementers inform the public of decisions and activities. Again we find wide variation, ranging from national information campaigns, to partnerships formed in local communities who have expressed an interest in hosting repositories. In between, there are local information centres and public consultations. Depending on in which stage the implementation process a country is, the public and local involvement varies. The idea of local communities forming partnerships with implementers under the auspices of national governments appears to be gaining traction in countries opting for voluntary siting. Some version of this idea can be found in Sweden, the UK and Canada. At the opposite end of public engagement we find countries in which local communities have lost confidence in the process, and where local democratic initiatives lack sufficient funds; examples are the Czech Republic and Spain.

In **column number six** we focus on **the process of siting**, one of the four socio-technical challenges focussed in this report, which some countries appear close to solving, while it has brought the implementation process to a halt in others. The column identifies in which stage the site selection process is: whether siting has begun; if a possible site has been identified; and in which stage local negotiations are.

The **seventh 'next step and critical actor(s)' column** pins down the country reports' conclusions regarding what needs to happen in order for the implementation plans to move forward. In countries with step-by-step programmes in place this is clearly set out and it is also obvious in countries currently lacking a strategy. Interestingly it is not always as clear. In France, for example, the introduction by law of the aspect of reversibility/retrievability into the disposal concept, while leaving the meaning of that notion still to be defined, complicates matters, and in Spain the construction of an interim storage facility is in focus at the moment. The column also tries to identify the actors who have to do something for the next step to be brought about. Again it varies, from the US administration needing to decide on whether to formulate the Blue Ribbon Commission's (BRC) recommendations into legislative proposal for congress, to local communities in West Cumbria having to decide whether to participate further in the UK siting process. A different range of actors are involved in deciding on the licence application for a repository in Forsmark, Sweden.

The **final column** truncates the findings of the InSOTEC studies by listing the **main socio-technical challenges identified** in each country report. As mentioned above there are more and different socio-technical challenges on the national level than we discuss in this synthesis report. The table aims to capture the specificity of national contexts in this regard. We can see that while the four challenges discussed here appear in different countries, there are also nationally specific challenges. Examples of the latter are: a failure of implementers to address the social in the Czech Republic; the competition between two repository proposals in Finland and deciding on the role of nuclear in the national energy policy in Hungary.

The table shows clearly that the only thing that all countries have in common is a commitment to geological disposal as the only feasible safe long-term disposal strategy for HLW/SNF. How they aim to implement it varies greatly, depending on a wide range of factors of different types: historical; political; economic and so on.

Table 1: Country Comparison – present state of HLW/SNF geological disposal

Country	Waste for GD (type, location)	Disposal concept	Dedicated policy/legal framework	Implementer character	Dedicated civil society engagement	Siting phase	Next step & Critical actor(s)	Socio-technical challenges
Belgium	High and/or long lived, including past reprocessing waste in central interim storage; (SNF status unclear)	Geological disposal in clay	No	State agency *ONDRAF/ NIRAS*	Not yet specified	Not started	Political (Federal Government) decision-in-principle on 2011 'Waste Plan'	Division of responsibilities; R&R; Monitoring & controllability; Preservation and transfer of knowledge & memory; RWM and advanced nuclear technologies
Canada	2.2 million CANDU bundles (SNF), +85000 annually; wet & dry storage at power plants	Deep geological disposal, bundles in containers; backfill; Adaptive Phased Management	Yes 2007 Adaptive Phased Management	Hybrid *NWMO*	Voluntary siting; public transparency	Expressions of Interest closed.	Further assessment of volunteer communities	None current
Czech Republic	SNF; dry casks; power plants	Geological disposal in granite		State agency *RAWRA*	Working group for dialogue about geological disposal	Not started	RAWRA to obtain consent to conduct geological research	Absence of the technical; Hierarchies and timing of the s/t; Natural conditions vs. engineered barriers; Political machineries
Finland	SNF	Geological disposal in granite	Yes Nuclear Energy Act 1989, Amended 1994 & 2008	Private companies *Posiva* & *Fennovoima*	Dissemination of information; Public gathering	Site confirmed		Construction license application by Posiva

Country	Waste for GD (type, location)	Disposal concept	Dedicated policy/legal framework	Implementer character	Dedicated civil society engagement	Siting phase	Next step & Critical actor(s)	Socio-technical challenges
France	Reprocessing HLW; 47,000m^3; La Hague & Marcoule	Reversible geological disposal in clay	Yes 1991 Bataille Law; 2006 Nat.,Plan for NWM	State agency *ANDRA*	Planned consultation process at national and local level	Site proposed	Public debate and law about reversibility	Retrievability / Reversibility; Site selection process Societal memory
Germany	SNF at reactor sites; reprocessing waste in central storage Gorleben	Geological disposal	Yes 2002 Atomic Energy Law; Amendments 2010 & 2011	State agency *BfS*	Undergoing reformulation	Not restarted	Create legal framework	Restarting siting on the basis of a criteria based, comparative procedure; R&R; long-term storage; Safety Case/ Criteria
Hungary	SNF interim storage Paks power plant	Geological disposal; WMPIA oversight and public information	yes Atomic Energy Act 1996, amemded Act CLI 2005	Not-for-profit organisation under auspices of state agency *PURAM*	Public information office; print & video newsletters; public meeting WMPIA local residents	Geological surveys of the Boda aleurolit formation	Develop HLW strategy	Energy policy, the role of nuclear energy Regimes, roles, responsibilities Options: Flexibility / path dependency International / regional solution
Netherlands	All waste, including reprocessing waste, in central interim storage	Retrievable geological disposal in clay or salt or international	Yes 1984, min. 100 years of centralised LT interim storage; national or international GD	Public company *COVRA*	Not yet specified	Not started	Develop generic safety case	Surface storage and/or GD; National and/or international RWM; R&R

Country	Waste for GD (type, location)	Disposal concept	Dedicated policy/legal framework	Implementer character	Dedicated civil society engagement	Siting phase	Next step & Critical actor(s)	Socio-technical challenges
Slovenia	SNF; wet storage Krsko; dry storage at reactor sites	Geological repository; copper canisters	Yes 1996, Strategy for long-term spent fuel management	State agency *ARAO*	Not yet specified	Not started	On-site dry storage	
Spain	SNF at power plants; vitrified reprocessing waste	Centralised interim storage; voluntary siting	Yes 2006 Sixth General Radioactive Waste Plan	Public company *ENRESA*	Seminars in nuclear communities; site visits; information meetings in candidate municipalities; Spanish Association of Municipalities in Nuclear Areas		Construct interim storage facility	
Sweden	Central interim storage, Oskarshamn	KBS-3: geological direct disposal, copper container, bentonite clay, crystalline bedrock; voluntary siting	Yes 1984 Law on Nuclear Activity; 1999 Environmental Code	Hybrid company *SKB*	NGOs; transparency forums; Local municipality programmes	Site selected	Licensing for repository construction	Political geography vs. physical geology; financing

Country	**Waste for GD (type, location)**	**Disposal concept**	**Dedicated policy/legal framework**	**Implementer character**	**Dedicated civil society engagement**	**Siting phase**	**Next step & Critical actor(s)**	**Socio-technical challenges**
Switzerland	About 100,000 m^3 in all (90 % LLW & ILW; 10 % HLW), interim storage at nuclear power plants or in two central interim facilities	Deep geological disposal; Sectoral Plan in 3 stages	Yes 2003 Nuclear Energy Act	Hybrid company *Nagra*	Stakeholders involved in all three stages of the Sectoral Plan	Closed, on-going negotiations	Spatial planning assessment of potential sites	Retrievability and pilot facility; Marking geological repositories/Knowledge transfer; Siting of surface facilities/Safety v. participation; Evolving knowledge during siting process: Different levels of knowledge at different sites, Necessary level of knowledge at different stages of siting
UK	Higher Activity Waste; 1000m^3 reprocessing waste; dry storage Sellafield	Deep geological disposal, vitrification	Yes 2008 MRWS White Paper	State agency *RWMD*	Voluntary siting; MRWS	Open, ongoing negotiations	Local decision to proceed	
USA	SNF 67000t +2000t annually; wet & dry storage at power plants	Deep geological disposal	No	n/a	n/a		Adopt strategy	Gather support for new strategy

3.2 Siting

The siting of repositories for deep geological disposal of HLW/SNF has become a major socio-technical challenge wherever it has been attempted. It has been extensively discussed and analysed in the research literature, as documented in another InSOTEC report (Bergmans & Schröder (eds.), 2012) and it was a key topic addressed in the CARL-project. It may seem superfluous to discuss it again in a project aiming to bring something new to the discussion. However, addressing it as a socio-technical challenge clarifies the concept and reminds us all that the issue is far from solved. At the time of writing, no geological repository for HLW/SNF has been licensed for operations anywhere in the world, although some national programmes appear to be nearing that stage.

The socio-technical challenge of siting has been encountered on the path to geological disposal in most of the countries embarking on it in the 1970s. From experts agreeing on the safety of a method in general and politicians finding it feasible, the realisation of this knowledge and ambition into an actual facility in a specific locality has proved very difficult. Attempts to site facilities where scientific and technical criteria have indicated the most promising geological conditions have been met with overwhelming public and political opposition. Some countries refrained from making more concrete plans for siting upon observing the controversies it generated elsewhere. Siting emerged as a socio-technical challenge and the public resistance made it obvious that the problem of HLW/SNF disposal could not be solved by science and technology alone. Governments all over the world learned that in democratic countries it is impossible to site geological disposal facilities without the consent of the affected publics.

While presenting a socio-technical challenge in all democratic countries throughout the 1980s and 1990s, siting has been addressed in different ways in different national contexts. Focussing on the 14 countries included in the InSOTEC project, we find that responses have ranged from a very quick re-consideration of the role of the public in Sweden, to successive US governments' decisions to press ahead with the Yucca Mountain site well into the 2000s. The Swedish country report describes how the implementer changed approach when running into public protests, to instead invent a new, voluntaristic process in the early 1990s. After years of negotiation, the localities initially suggested by the authorities, decided to come forward voluntarily. Sweden's change in approach re-configured the boundary between social and technical dimensions of the siting process and resulted in what has long been considered as one of the most successful geological disposal programmes in the world. In contrast the rigid stance taken in the USA resulted in failure of a potentially bigger magnitude than was the case in Sweden back in the 1980s. Political negotiations between the federal government and the state authorities led to the termination of the Yucca Mountain programme as the implementer was directed to withdraw the licence application in 2010. This brought the US siting process to a halt, after enormous investments had been made for years on investigating a location that is now potentially lost for further consideration.

While the socio-technical challenge of safety, discussed in the previous section, could be constructed as an issue possible to address through concerted efforts by scientists and engineers, siting mobilised another range of actors and connected with other things going on in society from the outset. Local residents and authorities become involved and cultural and political contexts impact on which actions are possible. In all countries with some discernible progress in their geological disposal programmes, some form of voluntary involvement by local communities has been instituted. Ways of working with local communities have been invented and refined by policy committees and implementers, one model originated in Belgium, in relation to LLW/ILW disposal. After a failure to site a facility in the 1990s the implementer ONDRAF/NIRAS involved university social scientists. This collaboration resulted in the concept of partnerships, involving local communities, to effectuate voluntary siting projects together with regard to short lived LLW and ILW. The Belgian partnership model has attracted attention from other countries which have considered it promising for developing new programmes for siting HLW and SNF repositories.

The re-conceptualisation of the role of local residents and elected authorities through active local struggles and in voluntaristic siting processes can be understood to signify the fact that technical projects are always social. Addressing the challenge by voluntarstic siting comprises a reorganisation of the social process and a reformulation of the technical concept. Although there will be some differences in potential and need due to the characteristics of the host rock, it is clear that technical concepts must change, from relying totally on the hypothetical ability of the host rock to act as a barrier against radiation (hypothetical because although theoretically sound and demonstrated in laboratory conditions, this belief has not been and cannot be tested in a full scale geological repository over thousands of years), to placing more emphasis on the role of engineered barriers in combination with geological properties. Engineered barriers in principle open for a search for a suitable, rather than perfect, site, as we see for example in the Swedish case.[8] The reconfiguration of geological disposal to overcome the challenge of siting into what can be considered an integrated socio-technical combination has showed promise as a way forward. In some countries one aspect of this policy rethink has been to move the responsibility for the process away from the technical community, in order to create democratic decision making procedures, by also enrolling social science knowledge. We mentioned the involvement of social scientists in Belgium, but an even more radical restructuring of programmes took place in the UK and Canada. In these countries the leadership was removed from scientists and engineers (Nirex in the UK and AECL in Canada), temporarily placed in the hands of very prominent individuals (comprising CoRWM and NWMO, respectively) who developed new, radically different, policy proposals that took social aspects seriously, and also involved social science knowledge. Upon the formal adoption of new policies other actors were designated as responsible for implementation: NDA in the UK and a reorganised NWMO in Canada. This reminds us that actors form different communities of practice and develop world-views and conceptual frameworks in relation to the work they do. New ways of addressing an

[8] Note that we do not claim that rethinking of the social causes the re-figuration of the technical; that would amount to social determinism. The anti-deterministic STS framework deployed in this report is not interested in the causation of the changes, but in their interdependence. In order for voluntaristic siting to be possible it must also be possible to construct geological repositories at different locations, and hence potentially in different geologies.

issue will be connected to the construction of new organisations and new actors are likely to work with issues in new ways. This demonstrates how socio-technical challenges prompt social change.

Siting is a socio-technical challenge that has, so far, prompted a number of countries to develop new social concepts for geological disposal which frame the technical implementation process. Although programmes have evolved since the 1970s and in many cases seem to be moving forward this does not mean that they have overcome this challenge. At the time of writing, no implementer in the 14 countries studied has been granted a license to begin construction of a geological repository for HLW/SNF. Siting remains a social-technical challenge, voluntarism has moved the process ahead in some places, but it is not universally adopted. Faced with opposition over siting, not all countries have focussed on overcoming that socio-technical challenge head on. There are different ways to move forward and the countries studied by InSOTEC have selected different paths towards geological HLW/SNF disposal.

National pathways towards geological disposal (Figure 1)

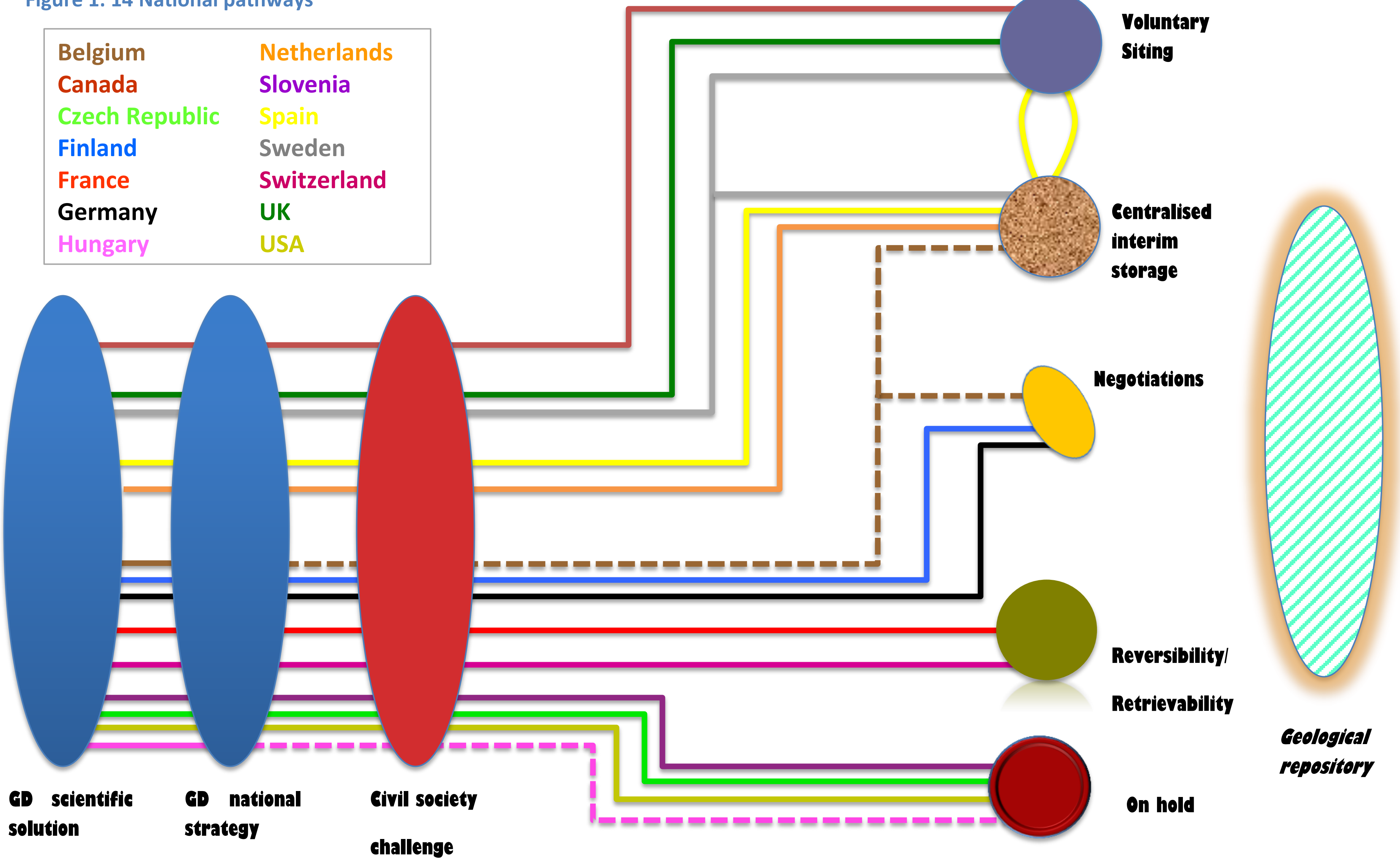
The country reports have facilitated the creation of a map to present the pathways towards implementation of geological disposal in the 14 countries, side by side. On the far left side of the map is a blue oval shape, symbolising the universal appreciation among the expert communities of scientists and engineers in the 14 countries, that deep geological disposal as the only method providing long-term safety of HLW/SNF. This is the first element in the historical trajectory of HLW/SNF geological disposal, originating in the 1957 US National Academy of Sciences report. The 14 nations studied in InSOTEC have all adopted this technoscientific solution as national strategy, more or less formally and at different points in time. This is symbolised by the coloured lines leading to the second blue oval shape. Each country has one colour according to the legend in the upper left hand corner. The dotted lines for Belgium and Hungary symbolises that, even without a formally adopted national policy, or no former, nor immediate plans for siting, all formally responsible actors are working towards the implementation of geological disposal as the solution proposed by the waste manager. The political adoption of the technoscientific solution of geological disposal resulted in a number of implementation and siting programmes, which were met with public opposition. Some national programmes were effectively halted by public rejection, for other countries the observation of such rejection elsewhere made them decide not to push ahead. The failure to implement geological disposal through the initial national strategies is symbolised by the red oval. From there on we can see how the national pathways towards HLW/SNF geological disposal diverge, the map symbolises the different states national programmes are in at present by the small circular shapes. One important point, clearly visualised in the map is that none of the studied countries are operating a geological repository for HLW/SNF disposal at this time. The goal of an operating geological disposal facility for HLW/SNF is symbolised with the oval shape of indeterminate colour on the right hand side of the picture.

At this point in time we can locate all the 14 countries at one of the small circles, each symbolising a distinct choice on the path to geological disposal. One circle symbolises **voluntaristic siting**. As mentioned in the previous section some countries have embarked on actively reconfiguring their policies in order to overcome the challenges. This has been done at different times in different ways in Sweden, Canada and the UK. Another option has been to create **centralised interim storage** while addressing the issue. For the sake of clarity, we have not included in this figure all countries with central interim storage facilities, but only indicated a number of examples. For a closer look at distinctive cases of interim storage as a pathway to geological disposal, we refer to figure 1a. To emphasise that the stages symbolised by the small circular shapes are not to be understood as mutually exclusive the grey line shows how Sweden decided on centralised interim storage as one part of the geological disposal programme and has a facility in operation while going ahead with voluntary siting. We can also follow the line symbolising the construction of two waste streams in Belgium where HLW is in centralised interim storage while negotiations about the status and managing of SNF are on-going. Development of centralised interim HLW/SNF facilities requires explicit decisions, as well as transport and management systems for a determined length of time. In contrast, the default position of storing HLW and SNF at the sites where it has been generated needs no political decision-making, but can be managed by the regulatory authorities overseeing the nuclear industry. Importantly, centralised interim storage solves the problem of 'stranded' waste, a problem that has become pressing with the decommissioning of nuclear power plants at the end of their lifetime.

Some countries are currently **negotiating** (or plan to) with other societal actors, authorities and/or institutions as they are moving towards geological disposal. The map does not distinguish between negations with local communities, elected authorities or regulators because the most important point is that the pathway is at a stage where other actors, many primarily defined in other networks than HLW/SNF management are involved. These other actors can, at least in principle, stop a programme, as the implementers and governments are aware, which is what is emphasised in the map, not who they are. **Reversibility/retrievability** has been brought to the foreground in France and Switzerland. This is another socio-technical challenge that we will address more in depth in the next section. In some countries the process is **on hold**. There are again different reasons for why national programmes have stalled. The important aspect captured in the map is that steps are not currently being taken to implement geological disposal. Whatever stage we trace a country to one thing is clear, no national programme has realised the goal of a geological repository for HLW/SNF, but geological disposal is currently considered the only possible endpoint for national HLW/SNF management programmes. This is symbolised by the gap between all current stages and the oval symbolising the realisation of a HLW/SNF geological repository.

One important aspect not captured by the map is the difference between the countries previously within the sphere of the Soviet Union and the rest. Slovenia, Hungary and the Czech Republic all shipped their spent nuclear fuel to Russia for reprocessing until the late 1980s. Although recognising the problem in the 1970s they did not need to develop HLW/SNF management programmes until the early 1990s. By then they opted for geological disposal as the preferred solution. However, it has been no easier to solve the issue of siting in the new democracies than in the old. Exacerbating the problem is a lack of trust in decision making processes, unstable political institutions and the economics of deep geological repositories.

Figure 1: 14 National pathways



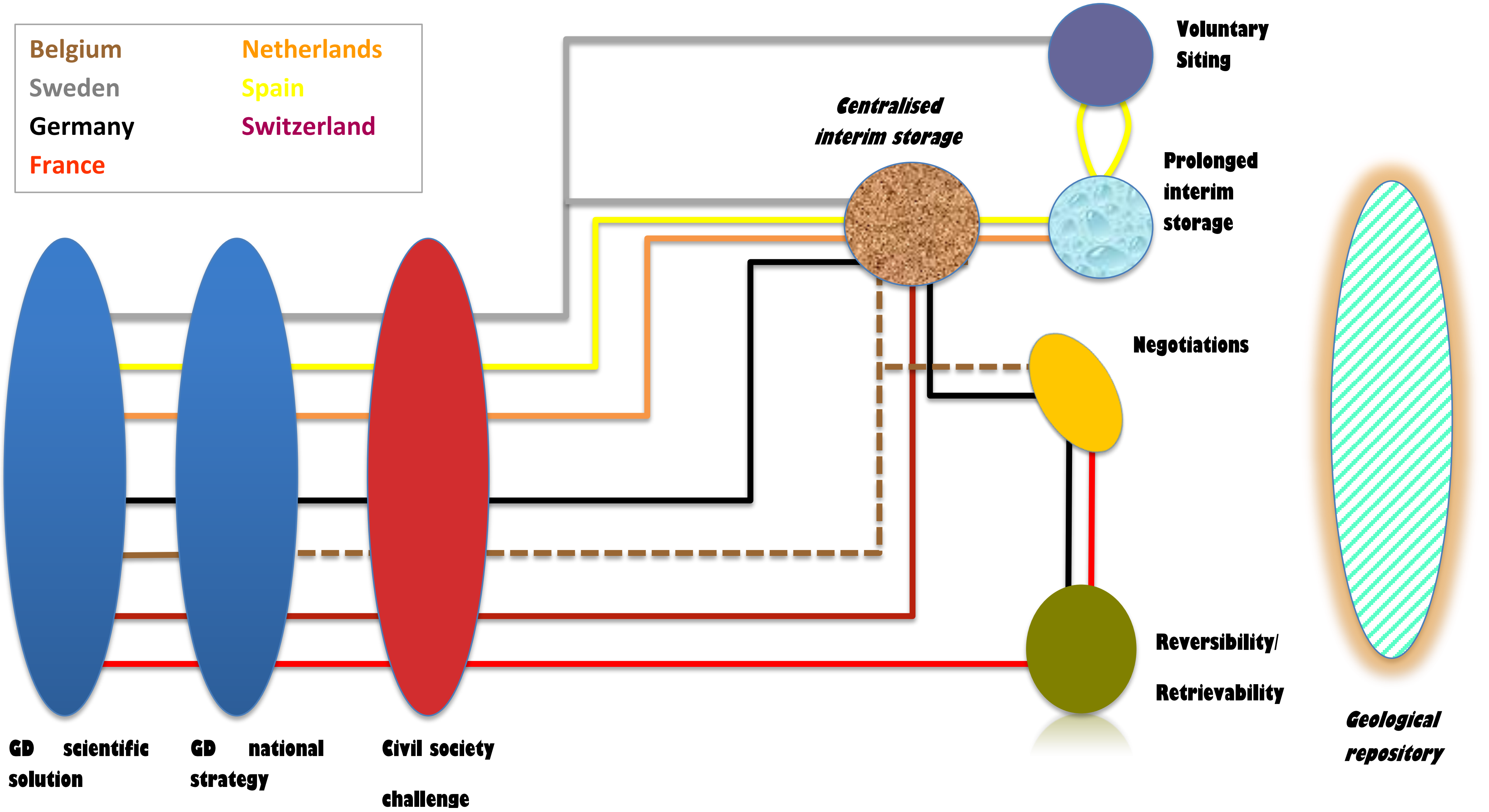
Close-up of seven countries (Figure 1a)

The map in figure 1 reduces the activities of the 14 countries to only five distinctive options, which can be understood as a function of scale. In order to show all 14 pathways it is necessary to 'zoom out' from the complex reality. However, if we focus on a smaller number of countries we can increase the resolution (zoom in) and capture more of the complexity of the real world. In figure 1a we zoom in on the six countries with centralised interim storage facilities, and on the ones opting for reversibility/retrievability, showing more complexity than what we could capture in the first map.

The increased resolution of this second map shows that the **Netherlands** and **Spain** have taken centralised interim storage one step further introducing the option of *prolonged interim storage*, thus pushing the issue of siting a geological repository a considerably ahead in time. In the Netherlands centralised interim storage is seen as providing an opportunity for the emergence of new political or technical solutions, for example, an international geological repository shared by countries with small amounts of waste, or new scientific discoveries in the area of transmutation. We can also see that Spain has chosen a voluntary siting procedure for their prolonged centralised interim storage facility, which has added complications as detailed in the country report. This option, however, raises a different type of siting issue from those of a geological disposal facility. The other countries with centralised interim storage facilities (**Sweden, Switzerland, Germany** and **Belgium**) have opted for a combined strategy of centralised storage and the pursuit of geological disposal through either voluntary siting, negotiations and/or adding requirements for reversibility/retrievability to the disposal concept.

As requirements for reversibility/retrievability have been institutionalised in **France** and **Switzerland** they have to be addressed and incorporated in the technical design concepts. Also shown on figure 1a, is that this involves additional parallel pathways. In France the nature of such a reversible concept is still up for discussion, as is the case for retrievability as a newly introduced requirement for the **German** concept, while in Switzerland, the legal obligation for retrievability is simply left to the waste manager to implement and the regulator to verify.

Figure 1a: Seven countries in more detail



3.3 Reversibility/Retrievability

The third issue that can be identified as a socio-technical challenge on a transnational level concerns the possibility of reversing the disposal, or retrieving the waste, from a geological repository. The country reports show that this is discussed among implementers as a socio-political demand, formulated by governments or potential host communities, rather than as a technical requirement. The Belgian country report notes, however, that arguments for reversibility put forth by social and political actors seem to put considerable focus on technology, for example, that technology may evolve in the future to offer better solutions than disposal and that reversibility adds to the safety of repositories, making it possible to remove the waste if unforeseen bad consequences would occur. In contrast, the technoscientific community seems to socially contextualise arguments for retrievability, for example, that risk perceptions may be different in the future and that definitions of waste may change. The emerging discussion in Belgium about this issue demonstrates its ability to unsettle the boundaries between the social and the technical.

Of the 14 countries studied in the InSOTEC project three – France, Switzerland and Germany – have formally decided to keep open the possibility of getting the waste out from the repository at some point in time in the future. In France this is brought about through a legal requirement of reversibility introduced by the 1991 law on nuclear waste as one of several options, but has since become a governing principle for later legislation. The country report highlights that the definition of reversibility varies depending on which actor is using the notion. As many other techno-scientific actors the French implementer ANDRA views reversibility as a notion based on a social logic, rather than a technical rationale. In line with this comprehension, ANDRA wants concepts to be created through dialogue involving both socio-political and techno-scientific actors. Currently two conceptions of reversibility can be discerned in the French discourse according to the country report, one identified as restricted and the other as extended. The restricted concept of reversibility proposes limitations in time and with regard to access. The process would be reversible until a decision has been taken to close the repository. In contrast the extended notion of reversibility has become equivalent with surface storage, from which waste can obviously be removed at any time. This concept constructs another social reality in which actors become obliged to continually learn and invent new, better methods to manage the waste since it is never out of sight or mind. In effect reversibility in this conception is constructed as the opposite of geological disposal. In Switzerland the requirement that the waste must be possible to retrieve from deep geological disposal has pushed the imagination in a different direction. One idea, that would require minimal effort in the present, is to make the waste retrievable through mining, which would be satisfied by the drawing of maps, detailing the layout of the repository. Furthermore the waste containers would have to be designed in a way that assures sufficient shielding with regard to potentially feasible retrieval techniques. Other ideas are more demanding with regard to repository design. The Swiss repository concept already incorporates the monitoring of a physical model of the facility, which can provide indications of what is going on in the actual facility over time.

In contrast to France and Switzerland, Finland and Sweden, the two countries understood to have solved the challenge of siting, have explicitly decided against reversibility as they understand the notion. The KBS-3 is a technical concept that will allow for the waste to be retrieved as long as the repository is in operation, i.e. while waste is being emplaced, after that it will be backfilled and permanently closed. Of the other countries some have decided not to decide, for example in the UK CoRWM recommended that the issue was left open for future decisions and the government followed this advice. However, the implementer, NDA, has begun to talk about retrieval and the regulator, EA, is also thinking about it, both anticipating a possible demand arising in negotiations with local host communities over the construction of a facility. Belgium adheres to a standard definition of geological disposal as being without intention to retrieve, but the idea of reversibility is still being considered in R&D projects and the terminology is evolving. In the Netherlands the issue has been discussed by political and scientific actors, who at times have judged it as incompatible with safety, in others as enhancing long-term safety. Currently reversibility and retrievability are required, but because the Netherlands have opted for prolonged interim surface storage while building up funds, carrying out research and exploring international final disposal solution, the issue does not present an immediate obstacle to programme progression.

An interesting aspect of the reversibility/retrievability conveyed by the country reports is the connection between national and international discussions among implementers. This demonstrates the importance of communication networks. The InSOTEC project includes a study of such communication, addressed as knowledge networks, focussing on an analysis of the IGD-TP as compared to other transnational networks focussed on knowledge sharing, but these relationships are also conducive to other types of study. Here we take a preliminary step for some further analysis in the next phase of InSOTEC, by taking a first look at virtual connections between implementers, regulators and their research partners. Albeit still superficial, this provides some interesting food for thought about the predominance and/or absence of certain actors at the European and the global level, and what this could implicate in terms of (national) agenda setting.

Virtual connections *(Figure 2)*

To approach connections between actors differently from the in-depth analysis of knowledge networks, this report illuminates virtual links using the issue crawler web mapping tool (http://www.govcom.org/index.html). The rationale for this is that the accounts of discussions about reversibility/retrievability in the country reports show that this issue has been extensively discussed in the techno-scientific communities, regardless of what national policies may require. In some cases it is obvious that while policy makers have tried to circumvent the issue, the implementers are still engaging with it. This implies that national programmes are not alone in setting the agenda for geological disposal discussions. This sparked our curiosity, not just with regard to the formal international interaction of national expert communities, but also about how national actors link together in communication networks. Links between websites can be understood to demonstrate to whom actors pay attention, there is no cost and very little effort involved in linking to a website considered interesting. Out of curiosity we ran the urls (web addresses) of all implementers and regulators in the 14 InSOTEC countries in Issue Crawler, which generated a map of web links between actors.

Issue Crawler mapped every site that more than two of the urls we defined as starting points linked to.[9] The arrows on the web map take us further from the sites directly connected to the starting points. Hence, if any of the url we fed in as input appears on the map it is because at least two other sites connected to it. This pertains to, for example ANDRA that is on the map, but was also a starting point.

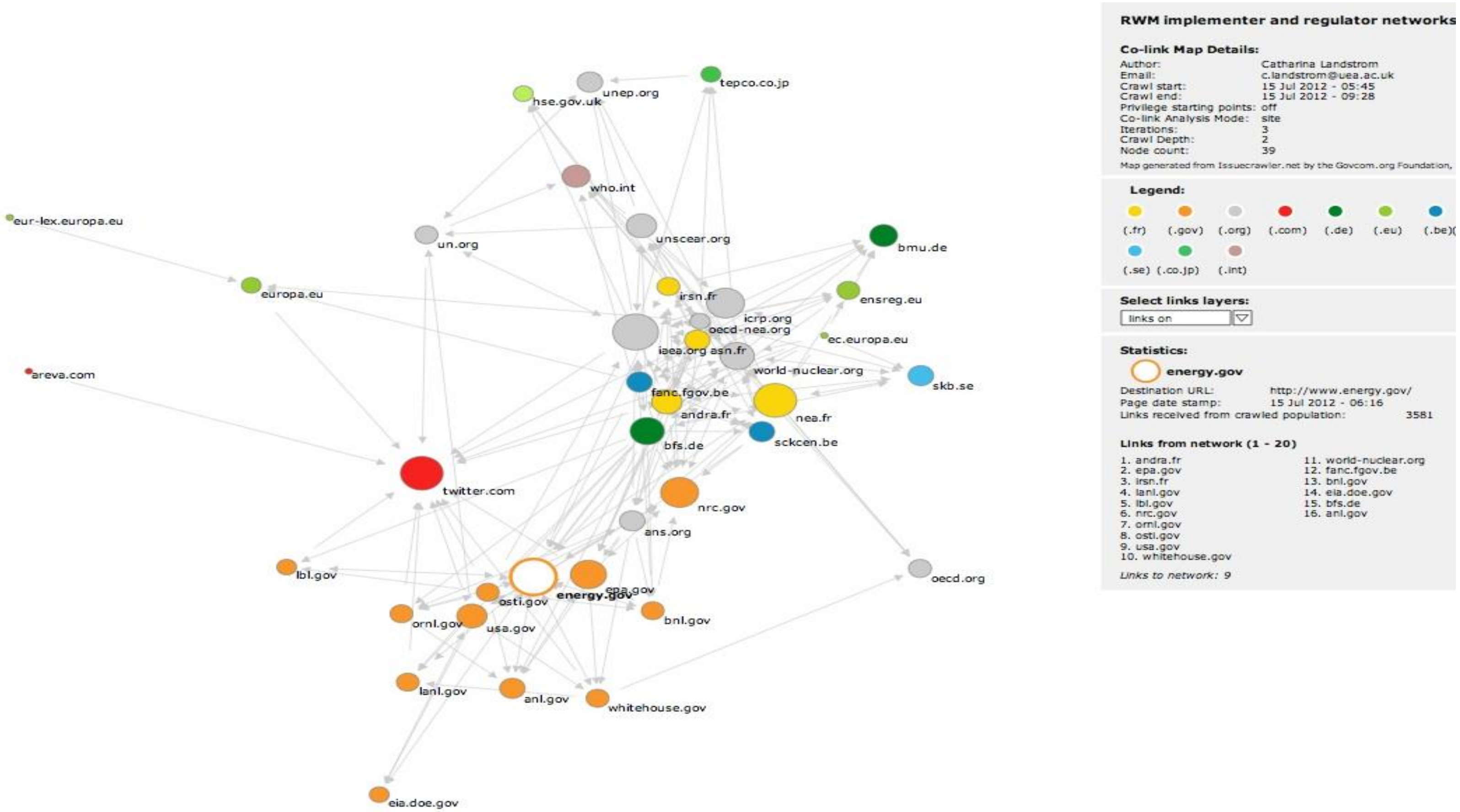
The web map offered both confirmation of expectations and some surprises. We expected links to international organisations and collaborative organs, which show up as grey circles with the .org suffix. This shows us that there are many international bodies involved with the issue of radioactive waste management, and that the implementers and regulators in the 14 countries studied are members of international networks. Also not surprising was the link to Japan, the Fukushima disaster has impacted on the understanding of these issues globally. Somewhat surprising was the low number of European connections: there are no links to European government departments. Knowing that all regulators and the majority of implementers are public bodies, we can speculate that the communication is predominantly national. If each national regulator and each national implementer link only to each other, it would only generate one link and not show on the map. We were surprised by the extent of links to US government websites. This may reflect an interest, at the time of mapping, in what the Blue Ribbon Commission on America's Nuclear Future would conclude and/or what is going on with the Yucca Mountain programme.

Another surprise was that the research intensive implementers in the European nations do not visibly link to national scientific organisations not dedicated to this issue (for example, National Academies of Science), or to universities. The lack of visible links to public organisations in science and higher education could indicate a lack of engagement with this issue outside of the implementer-regulator-community networks in Europe. This would resonate with concerns that the knowledge base is eroding and the recruitment of the next generation of experts with adequate education, knowledge and skills, could become a problem, which were expressed by some interviewees representing implementers and regulators, presented in country reports.

The web mapping has been a very tentative exercise and the interpretation rather speculative. Looking at it we have to keep in mind that it only captures communication links known to the sections in the organisations responsible for the websites. However, we do note the possibility of capturing some of the connections, or lack thereof, between actors, not otherwise visible, in this way and hope to be able to explore the approach further in future InSOTEC reports.

[9] Detailed information about Issue Crawler at http://www.govcom.org/Issuecrawler_instructions.htm

Figure 2: Web map – implementer & regulator connections



3.4 Managing the long-term

The fourth socio-technical challenge we will address in this synthesis report is less contentious than siting and reversibility/retrievability. On the one hand, there is the straight forward question asked by implementers and other concerned actors about how they can make sure that knowledge of HLW/SNF repositories and their risks are communicated to future generations for as long as the danger persists. On the other hand, the socio-technical approach alerts us to the inevitability of any technical solution and the preservation of long-term memory as being unavoidably entwined with the social organisation. In this section we will first look at the deliberations of implementers on the preservation of memory, thereafter we will address the issue of long-term governance of HLW/SNF repositories.

Preservation of social memory

As implementation strategies are moving forward the need to convey the knowledge about the hazards to human health and the environment posed by a geological HLW/SNF repository over tens or hundreds of thousands of years is likely to emerge as a major socio-technical challenge. The timeline for the social memory needed surpasses anything known in human history. The modern human has been around for about 50.000 years according to the archaeological record. The communication of the threat posed by a HLW/SNF disposal site would need to work for double that time into the future. How societies may change in that time-span cannot be meaningfully imagined.

How do you send the message into the future? The discussion in France is described in the country report, the implementer ANDRA has taken the lead in exploring ways in which knowledge can be materially and socially preserved. So far the work has elicited knowledge about history, archaeology, art and libraries, in addition to the in-house expertise on radioactive waste management itself. Analysing ANDRA's initiative, the country report concludes that creating social memory lasting for generations is a socio-technical challenge that will bring together very different issues and knowledges since it concerns both the capacities of physical materials and assumptions about future human societies. The issue has also been discussed in Belgium, the country report details the views of researchers engaged in programmes conducted by the implementer ONDRAF/NIRAS. The question here surfaced in relation to retrievability, as it was pointed out that this will only be an option if future generations have access to accurate and specific information about the disposal system. Long-term memory is also connected to prevention of repository intrusion; beyond the issue of securing a facility against intentional attack there is also a risk of unintentional intrusion if physical markers of the site have lost their functionality. The Belgian report also reminds us that there are different views on this issue, reflecting opposing valuations of geological disposal. Greenpeace, for example, disagrees with the idea of geological disposal being safe. They consider the problem with preserving memory of something that is no longer present and visible over thousands of years impossible, insisting that passive safety will inevitably lead to social oblivion, which will increase the risk for future generations.

A very different approach to the preservation of social memory has been put forward in the North American discussions. Drawing on experiences of preserving knowledge about the land across generations by means of established oral traditions, Canadian First Nations and Native American Tribes have suggested that traditional aboriginal means of knowledge transfer across generations may be better at preserving memory about the risks posed by repositories across generations. If North American implementers choose to pursue this possibility, which is not inconceivable considering the number of expressions of interests in hosting a repository put forward by First Nations in Canada, the reconfiguration of the boundary of technical and social in the resulting socio-technical combination could surpass anything seen in the modern world.

Regardless on how the socio-technical challenge of memory is eventually addressed the solution will be something that cannot be imagined today, since none of the means of communication we have seen so far in human history has the capacity to perform over the necessary time. A fact that emphasises the lesson recurring in geological disposal of HLW/SNF: this is a process with dynamics far too complex to be reliably predicted or controlled by political decision-making. This brings us to the issue of long-term governance, bound up with memory and, in our mind, at least as important and probably more pressing to address.

Long-term repository governance

Approaching the issue of the long-term from the socio-technical analysis developed in the InSOTEC project we note an intriguing absence of discussion of long-term management and governance of repositories. The discussion of preserving memory seems to assume that repositories are closed down and everybody walks away. Then millennia of no habitation would follow, where after new people arrive. This imaginary is inherited from the first generation of geological disposal policies, part of the 1957 idea, presented by scientists. The initial concept of geological disposal comprised both the isolation of waste in geological formations and its geographical separation from human societies. The latter featured more or less explicitly in the techno-science dominated policies that failed to overcome the socio-technical challenge of siting. The voluntary siting processes that presently show some promise of leading to the implementation of geological disposal are major game changers in this regard. It is, for example, not particularly likely that the population of Forsmark in Sweden will pack up and leave when the envisaged repository is completed (unless of course something goes horribly wrong with it), at least not in the first few centuries ahead.

While there is very good reason to reflect on the question of eventual loss of memory and major changes in human settlement due to climatic changes (e.g. major ice sheet development in the northern countries), this reflects totally different time scales. In terms of geology, the long-term relates to hundreds of thousands, or even millions of years, whereas with regards to human activity, a decade already counts as long-term. It therefore seems just as important to reflect on and discuss the whole period between now and that extremely long-term. Given the new situation, in which it looks as if repositories will be built in the relative vicinity of local host communities, the extreme long-term seems less of a pressing issue than the much nearer future in which repository operations and closure is scheduled to take place. However, while national programmes provide clear guidelines for how to negotiate and decide on the siting of repositories, they are less clear on long-term governance. From the perspective of this report, approaching geological disposal as a socio-technical combination addressing the socio-technical challenge of siting, we can discern three areas that may become issues in the long-term regarding the governance of repositories, in particular, though not excluded to, those sited through voluntary means.[10]

One of the issues concerns who will be able to call for changes in, or termination of, a geological repository programme if insurmountable technical or social obstacles emerge? The possibility of technical surprises has been demonstrated in the context of geological disposal of other radioactive waste categories, ranging from brine necessitating a spatial repositioning of WIPP in the USA, to the need to retrieve and relocate the waste disposed of in the Asse salt mine in Germany. Even if the latter was never authorized as a repository facility, the general perception is one of disposal gone wrong, attributable to political and administrative factors, as well as geotechnical problems. The Yucca Mountain project in the USA was terminated by the political administration that considered it to be politically non-viable, a decision currently challenged in courts of law. These are examples of technical and social problems forcing changes to plans. With regard to the long-term governance of deep geological repositories it is necessary to construct democratically viable and robust decision-making frameworks, specifying how to manage obstacles and under which circumstances programmes are to be terminated.

A second question arises when a facility has been successfully constructed: Who will decide on which waste and how much of it, to accept? As we have seen waste categorisations are not fixed and may change during the period of repository construction and operation. One axis of fluctuation is the disposal of civilian and military waste, as national decisions to co-locate or to keep them separate might change. Another concern is whether reprocessing is on the agenda or not, which impacts on the designation of SNF as resource or waste, which makes a big difference for the volume and characteristics of the waste, issues of transport, costs, etc. A further concern arises with regard to the possible expansion of repositories in relation to original plans and possible changes in the role of nuclear power in national energy policies. Procedures for making decisions about what can go into a repository need to be in place before issues arise and they need to be transparent.

The third and last question we can identify follows when the emplacement of waste is reaching the planned limit: How is the decision about the closure of the facility to be made? The current strategies anticipate closure of filled up repositories more than 150 years into the future at the earliest, but most do not define how the decisions to close a facility will be taken. This is important to discuss, particularly since the creation of partnerships for HLW/SNF geological disposal and the introduction of the notion of reversibility, change the societal decision-making structure. It is obvious that such decisions will be taken by future generations and that things may evolve. Therefore we do not point to the drafting of decision making procedures to be put in place within 150 years from now, but to

[10] That these issues have already been discussed in Finland indicates that they are likely to emerge as challenges as repository projects move ahead.

the need to define pathways to gradually prepare for such decision, in other words, to develop the concept of stepwise adaptive processes (NEA, 2004) beyond the stage of siting. This presents a significant socio-technical challenge, as it requires ways of follow-up and monitoring, as well as the capability to learn from experience. However, at present, this issue does not seem to be included directly in discussions on the long-term.

4 Conclusions

The aim of this report has been to synthesise the findings of the 14 InSOTEC country reports identifying remaining socio-technical challenges to the implementation of geological disposal of radioactive waste. Focussing mainly on HLW/SNF disposal as the most challenging task on the transnational level at this time, we began with clarifying the source term. Tracing the genealogy of the notion of socio-technical we found that it had multiple uses and meanings in previous social science endeavours. The present usage was defined in relation to the particular task and the conceptual underpinnings in science and technology studies. Although elaborated for use in this synthesis it was emphasised that the concept needs to be kept open in order to enable further insights. Keeping the concept open allows for variations in meanings, depending on the level of analysis, for example, between the national and the transnational. Variations can also relate to the temporality of a study, if it focuses on the past, present or future. We consider one aspect of the InSOTEC project to be to articulate the notion of socio-technical challenge in ways that connect elements in novel ways and create new meanings.

The articulation of the notion of socio-technical challenges in this report was intended to capture processes occurring on a transnational level and reconfiguring the boundaries between what is considered social or technical, at a specific time. This definition brought to the forefront four issues identified across the country reports: safety; siting; reversibility/retrievability and managing the long-term. The first synthesising move is already visible in the selection and labelling of these challenges, they are not identical to those of the country reports. Discussing these socio-technical challenges we have not repeated the analyses of the country reports, but focussed on characterisation, using examples from different countries.

With regard to **safety** we found that this was the primary socio-technical challenge which has been addressed through a technoscientific hypothesis of deep geological disposal. The trust in this hypothesis in the science and engineering communities appears to make it hegemonic, shaping policy and public discourses. As of yet, it has not been possible for anybody to argue for different long-term solutions in a way that can be taken seriously by the technoscientific experts. Although proposals have been introduced for alternatives, such as prolonged interim storage, and partitioning and transmutation technology, consensus on geological disposal being the only viable long-term option, remains. The proposed solution of HLW/SNF geological disposal has been subjected to extensive research since its introduction in the late 1950s and it has become much more sophisticated, underpinning specific proposals for repository design. However, the hypothesis has not and cannot be exhaustively proven until a HLW/SNF repository has been constructed and functioned as expected for the duration of the risk. Since that might take hundreds of thousands of years, the hypothesis is in effect untestable. The fact that no repository is yet in operation prompts the present analysis to regard deep geological disposal of HLW/SNF as a socio-technical combination addressing the socio-technical challenge of safety, rather than as a technology solving a problem. Whether geological disposal will solve the problem in its totality is not yet known, but it is an idea that has shaped science, engineering, policy and politics in all countries with HLW/SNF over the last half century. We compared the ways in which the 14 countries studied in the InSOTEC project developed their programmes for HLW/SNF geological disposal by placing them in a table capturing their current situations with regard to eight issues: waste; concept; policy; implementer; civil society; siting phase, next step and remaining socio-technical challenges.

In the reality brought about through the commitment to geological disposal of HLW/SNF a major socio-technical challenge that remains unsolved in most implementation programmes is **siting**. The country reports show how the selection of sites by national governments, following recommendations from the techno-science community, has triggered extensive public opposition, wherever attempted. Government or implementer led, top-down, siting of HLW/SNF repositories has failed in all InSOTEC countries that have tried it, at different points in time, leading to policy re-orientations. In some countries negotiations with local communities enabled implementers to move forward, in other more radical re-formulations of policies were necessary. Everywhere governments have found themselves forced to accept a more active role for local communities affected by geological disposal. The involvement of other social actors range from voluntary siting in which local communities express interest in hosting a repository, to elected local authorities having veto rights in relation to repository construction. In some countries siting has been relegated to the future as more pressing matters, such as safe interim storage, are being addressed. Other countries are in the process of deciding on siting procedures. The different positions of the InSOTEC countries, following from addressing the socio-technical challenge of siting were captured in two maps of pathways, at different scales. We could see that some countries are pursuing voluntary siting, some are developing centralised interim storage, in some countries implementers are in negotiations with other actors, some countries are elaborating their technical concept for reversibility/retrievability and in a few the process is currently on hold, for a variety of reasons.

The emergence of **reversibility/retrievability** as an issue requiring address in siting and design processes prompted us to regard it as a socio-technical challenge in its own right. It is extremely interesting because it appears to defy the original concept of geological disposal as providing passive safety through isolating the waste physically and separate it from humans. The country reports account for distinct national approaches to this issue which are discussed among implementers, regardless of whether national policy demands it. The extent of the discussion encouraged us to consider international communication among involved actors. An aspect of geological disposal already empirically addressed in InSOTEC we could afford a more experimental approach and explored virtual connections in a web map, which enabled some reflection regarding the dominance, or absence, of certain actors on the international scene, and what this could implicate in terms of (national) agenda setting in research and policy. We will return to this type of on-line exploration later in the InSOTEC project.

International speculative deliberation is what prompts us to identify the **long-term** as a socio-technical challenge. The country reports identify the preservation of knowledge and memory of repository design and the hazard posed as an issue identified by implementers and other concerned actors. Deliberations involve experts from the humanities, as well as physical scientists who discuss the durability of both signs and the symbols on them. Not yet an acute issue it will become important if repository construction progresses as planned. However, before they do we think other questions will prove more pressing.

Synthesising the insights from the country reports using the STS approach outlined in the introduction has alerted us to the radical reconfiguration of geological disposal following from voluntary siting. One of the consequences is the need for long-term governance of repositories. While the original concept of geological disposal comprised geographic separation and national government decision-making, voluntary siting brings HLW/SNF repositories into democracy. Sited in host communities, powering local economies and embedding in local cultures, geological repositories will need clear governance structure to enable democratically acceptable decision-making in the operational and closure stages, long before social memory becomes an issue.

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5.1 Preface on InSOTEC

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