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Addressing the Long-Term Management of High-level and Long-lived Nuclear Wastes as a Socio-Technical Problem: Insights from InSOTEC

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Executive Summary

The European research project 'International Socio-technical Challenges for implementing geological disposal' (InSOTEC) focused on the analysis of the complex interplay between what are typically seen as distinct technical and social dimensions of radioactive waste management, in particular in the context of the design and implementation of geological disposal.

Geological disposal is today the internationally preferred technical option for the long-term management of higher-activity and longer-lived radioactive wastes. It has also been the focus of societal concern and, at times, controversy. Geological disposal concepts have evolved, not only because of developments in scientific and technical knowledge, but also as a consequence of debates about how to integrate societal values and concerns into the technology. Illustrations of this are the incorporation of the notion of retrievability into the Swiss geological disposal concept and of reversibility into the French concept. Geological disposal should therefore be understood not simply as a technical but as a *socio-technical* concept, the meaning and characteristics of which are negotiated and value laden, inherently dynamic and subject to change. This has important implications for our understanding of the challenges faced by radioactive waste management.

InSOTEC began from the premise that the scope of social-scientific research on radioactive waste management should be expanded to include studies of the social aspects of science and technology and of the technical translation of socio-political requirements. Rather than focus on social impacts and acceptability and on citizen participation as a way to express democratic values or to facilitate programme implementation, therefore, InSOTEC views wider societal involvement as also having the potential to bring in alternative perspectives that could contribute to the creation of new knowledge and to the identification of new solutions which, in turn, could influence technical choices.

InSOTEC draws attention to the tendency to define key challenges for implementing geological disposal as social problems, consequently moving the technical aspects out of the public domain. It encourages implementers, regulators and the techno-scientific community working on repository design and issues related to the safety case to reflect on the implications of this and to allow more explicitly for processes of technical problematisation by inviting concerned societal actors, such as citizens in potential host communities, to participate more explicitly in the technical debate. It also encourages societal actors to contribute to technical debate beyond discussing the local impact of implementation of a specific technology on a specific location.

InSOTEC therefore proposes a socio-technical perspective on the implementation of geological disposal as a (scientifically) controlled, open-ended exploration towards a possible solution. It makes the case for more integrated, interdisciplinary research and development (R&D) projects on radioactive waste management in general and on geological disposal in particular, bringing together researchers from natural sciences, engineering, social sciences and humanities. Viewing the problem of geological disposal as inherently socio-technical also challenges, however, the division between experts and 'non-experts' when determining the nature of the problem and the potential solutions, demanding not merely an interdisciplinary but a transdisciplinary approach.

These conclusions and their implications are elaborated briefly in the summary that follows.

Beyond a stepwise approach

Separating the long and complex process of implementation of geological disposal into smaller steps helps to structure the decision-making process, making it seem more manageable, but can become a significant obstacle to reflecting adequately on the entangled relationship between what are treated as distinctly technical and social aspects. The stepwise approach may have unintentional consequences if technical issues are in large part excluded from public discussion and public participation is therefore reduced to selected parts of the process. A phased approach should therefore be designed and implemented so as to retain sensitivity to the socio-technical complexity of the project and to ensure meaningful integration of social demands in technical developments.

Recognising the need for participation beyond organised forms

When public participation in long-term radioactive waste management takes place, it is typically in a form of invited and organised dialogue. The question of what (and who) is excluded from such activities is considered as being outside the democratic process. This is particularly true for protest and conflict, which are often regarded as alternative to and even incompatible with democratic public engagement. However, invited and organised dialogue risks excluding sections of the public and preventing them from contributing to the development of the proposed technology. Forms of organised participation may continue to be a useful tool but the democratic process can extend participation more widely and across successive phases of a planning and implementation process.

Changing the approach to conflict

Conflicts over technology are often interpreted as resulting from a poor appreciation by non-expert protagonists of the technical basis (the so-called 'deficit model') or to ideological views. Such conflict may, however, be seen as providing an informal technology assessment of the problems raised by a technical solution. From this perspective conflict can be constructive, highlighting potential weaknesses of a proposed technology and enabling anticipatory adjustments. For it to do so, a learning process with a long-term perspective is needed, which in turn requires procedures for capturing problems raised in different arenas and for translating them into new R&D questions.

Overcoming disciplinary barriers

The complex socio-technical problem of geological disposal cannot be resolved through a system of compartmentalised scientific knowledge. Inter- and transdisciplinary research can contribute to overcoming disciplinary limitations and provide opportunities for meaningful involvement of stakeholders. To establish this, researchers and research institutions should be actively encouraged to venture beyond their disciplinary boundaries, in dialogue with societal stakeholders.

Embracing flexibility and avoiding technological 'lock-in'

It is unlikely that we are able to foresee all of the problems or contextual changes that might arise over the timescales associated with any long-term management strategy for high-level wastes. Ensuring effective long-term democratic governance is therefore one of the specific challenges facing radioactive waste management. This calls for openness and flexibility to allow for developments in science and technology as well as in political and societal values and objectives. Flexibility therefore requires the maintenance of the capacity for technical innovation, which implies the continuation of research programmes as an integral part of the implementation process. A democratically-governed process of continuous improvement demands that both the implementation and accompanying research programmes are organised so as to engage society at large, and the most directly concerned actors in particular, in determining what questions remain and how they should be addressed.

Contents

1. Introduction

This report summarises the lessons to be drawn from the three-year collaborative social sciences research project 'International Socio-Technical Challenges for implementing geological disposal' (InSOTEC).[1,2] Adopting an approach that is relatively novel in this context, the project focused its investigations on *the complex interplay between* what are typically seen as distinct technical and social dimensions of radioactive waste management (RWM), in particular in the context of the design and implementation of geological disposal. The aim of the InSOTEC project was not to arrive at a prescription for facilitating the implementation of geological disposal, but to foster and deepen the growing awareness of the interaction between social and technical aspects of RWM that has been evident within the technical expert community by providing stakeholders and experts of all kinds with a better understanding of the processes that shape the challenges which confront them. The report brings together insights for radioactive waste management (RWM) that have been generated within the different research strands (or Work Packages) of the project and offers observations on their implications for practice, addressing in particular the processes of research and development (R&D), public and stakeholder involvement in RWM, and long-term governance of geological disposal of higher activity radioactive wastes.[3,4]

The InSOTEC project set out to contribute to *understanding the nature of the challenges* faced by reflecting on the social dimensions embedded - but often unacknowledged - in a management approach that is seen by implementing organisations as being technically-based and therefore objective and, in its fundamental assumptions, non-contestable. InSOTEC therefore engaged with the problem of geological disposal by studying and describing the processes of implementation without assuming an inherent separation between social and technical aspects of such processes. The project went further by viewing the process of defining what constitute 'technical' and 'social' aspects as being inherently dynamic and therefore subject to change.[5] What this means in practice is that, although often treated as not only distinct but also as relatively stable, 'technical' and 'social' are inevitably unstable categories that constantly reconfigure themselves. This shift in perspective has important implications for our understanding of the challenges faced by RWM. It highlights, for example, how our understanding of a technology's performance – what a certain technology does or doesn't do for us – is shaped and re-shaped in relation to expectations and purposes that are themselves constantly being revised, disputed, negotiated and adjusted. It also has implications for our understanding of the relationship between science & technology and the practice of democracy. Furthermore, although this entails public and stakeholder involvement at different stages of R&D and policy making in relation to the long-term management of higher-activity radioactive waste, the approach that is presented here points to a role for social science that extends beyond that of providing models and methods for stakeholder engagement or researching conditions for public acceptance.

Geological disposal illustrates very well the processes that have been described. A dedicated expert community has been working for decades in relative seclusion from the wider society on a particular technical solution, the boundaries of which have been set mainly by technical experts and scientists. When confronted by a society reluctant to accept unconditionally the implementation of this solution, the challenge was initially considered to be a social and political problem, not a problem with the technology that was being developed. While this was understood as a challenge in need of proper treatment and research, it was seen as being quite separate to the existing scientific and technical R&D and management programmes, reinforcing within the field the divide between social and technical aspects. InSOTEC challenges this taken-for-granted and apparently common-sense distinction between technical and social aspects as the starting point; instead it aims to illuminate the nature of the challenges encountered by radioactive waste management and the dynamics at play by focusing on the interconnectedness and reciprocal influence of these two aspects.

Section 2 of the report outlines in more detail the conceptual basis of the socio-technical perspective that is advocated in this report. It provides the reader with an overview of the social scientific ideas and analytical approach that have informed the broad orientation of the research, as well as the detailed approach taken to many of the individual case studies. It also outlines a new role for social science. Section 3 then addresses the question of how this alternative socio-technical approach to thinking about the relationship between the social and the technical might be supported in the development of R&D programmes and governance structures for the long-term management of higher-activity radioactive wastes. Finally, Section 4 summarises specific implications and recommendations that have been drawn from the research.

2. Understanding the Relationship between Social and Technical Aspects of Radioactive Waste Management

This section establishes the conceptual basis of the report by distinguishing between two different perspectives on the relationship between social and technical aspects of radioactive waste management. The first of these perspectives, which sees social and technical aspects as being quite separate, characterises the view widely held in policy, implementer and stakeholder circles and informs much of the previous social science-based work on this issue. The second perspective, which offers an alternative understanding of social and technical aspects as being closely interrelated, is the basis of the InSOTEC project. What is therefore advocated in this report is a more reflective (and, we would argue, a more realistic, flexible, and nuanced) way of representing 'the technical' and 'the social', one that acknowledges complexity, rather than reducing it. This alternative perspective is elaborated by linking the two elements in the concept *socio-technical*, but developing that notion further than the sense in which it is typically used in the context of radioactive waste management. This provides the basis for an alternative approach to identifying and addressing the challenges that are faced by long-term management of higher activity radioactive waste, which is outlined with illustrative examples in Section 3 of the report.

Social science has often been mobilised to overcome actual or perceived public and/or political resistance to the implementation of geological disposal. Not so long ago, an idea ultimately prevailed as evidence in the nuclear community: considering the 'technical problem' largely solved, the management of higher-activity radioactive waste has now become foremost a 'social' problem, or, as it is often referred to, a problem of 'social acceptability'. While geological disposal of radioactive waste is considered by most experts as an inescapable solution, the exploration of this technical option through underground laboratories in many cases gave rise to violent controversies on the sites concerned. This is why, after having long been called a 'technical' problem, the disposal of radioactive waste has in the last years received the label of 'complex problem', meaning 'technical-AND-social' problem that needs to involve a plurality of scientific disciplines. This reformulation has led to a proliferation of studies and seminars on the 'social aspects' of this issue, which would complement the existing and well-established efforts focused on 'technical aspects'. One example of this particular trend is the OECD Nuclear Energy Agency's (NEA) Forum on Stakeholder Confidence (FSC), which was set up in 2000 to "facilitate the sharing of experience in addressing the societal dimension of radioactive waste management", and to "explore means of ensuring an effective dialogue with the public with a view to strengthening confidence in the decision-making processes" (FSC 2014). Another example is the Social Science Research Programme that the Swedish radioactive waste management organisation, SKB, ran from 2004 to 2010 and which was initiated to "meet the need for knowledge regarding the many major societal issues associated with the management of spent nuclear fuel" (SKB 2010). One could argue therefore that there is now a 'social demand' on this subject, which results in repeated calls to the social sciences and humanities. This project is part of a larger response to this demand.

2.1 Two Perspectives on the Relationship between Social and Technical Aspects

There are, however, multiple ways to conceive a possible contribution by social sciences to radioactive waste management. Lits (2013) for example distinguishes three ways in which social sciences are associated with the question of radioactive waste: as 'complementary experts' (Bonano et al. 2011, cited in Lits 2013), focusing on the question of social impact and acceptability; as mediators or designers of deliberative processes; and as 'critical experts', reflecting on the development of technology and its governance, thus contributing to technical innovation in itself. These three roles are not necessarily mutually exclusive. Nevertheless, such a classification makes clear that the notion of 'social aspects' of radioactive waste management encompasses many different things, including the technology itself, and that these are treated differently depending on the way the issue is framed or problematized.

The position taken here is to take from Lits' typology a distinction between an emphasis on 'the social around the technical' and on 'the social within the technical'; that is to say a distinction between a focus on social impacts and acceptability (usually referred to as the 'social context'), and a focus on the development of technology or technical innovation in itself. We leave aside Lits' third category because mediation and deliberative processes can be utilised by both of these approaches. In the remainder of Section 2.1 we therefore describe the two clearly distinguishable approaches to studying the relationship between technology and society.

Perspective 1: Social Aspects are Part of the Context to Technical Aspects of the Problem

This first perspective is typical of many studies produced in the past, often at the request of the nuclear industry itself, on the 'social implications' of nuclear energy and in particular on problems related to radioactive waste management. A multitude of disciplines from the social sciences and humanities - psychology, sociology, psychoanalysis, ethnography, communication analysis, etc. - have been called upon by decision makers to address issues such as risk perception and risk communication, decision making processes, attitudes, social norms and values, economic impact, etc. While differing in methods and explanatory models, these types of studies share at least three common features.

A first characteristic is that they start from a division between what is 'technical' and what is 'social', without questioning this separation as such. What constitutes the 'problem' that justifies sociological or psychological studies for many decision makers is not so much how to develop technical concepts and decisions in the nuclear field, but why 'the public' resists to these technical projects or decisions. The classic distinction between 'real risk' and 'perceived risk' is a typical example of this thinking, locating the causes of controversies in the idea of 'biased' perception of risk, while leaving the technology unexamined (Bauer 1995).

The second characteristic of this perspective is that, as a consequence of the fundamental distinction that it assumes, it tends to focus on understanding the causes of the divergence between the views of experts and those of citizens. In other words, the goal of the social sciences is often seen as being one of diagnosing the causes of controversy without engaging with or questioning the technological concepts that are in play. Again, depending on the discipline, the explanations may focus on a variety of influences, such value systems, social or cultural affiliations, education, active and vocal minorities, or the mass media. The causes of controversies are, however, largely disconnected from technical choices (Barthe & Jouzel 2010).

Thirdly, therefore, the usual conclusions of such studies do not look to the nature of the technical solutions as being a cause of conflict and as part of the problem. Technical aspects are therefore not directly questioned. Hence responses typically focus on education, information, or communication strategies, intended to increase trust and a sense of safety. The idea is often to avoid 'irrational' public reactions, even though this expectation is usually unfounded.[6] This is undoubtedly a very simplistic, perhaps even a caricatured account of this approach that will not describe every case but the aim is to highlight well-recognised tendencies which not only affect our understanding of the problem but also have important political effects in that they can help to neutralize criticism of technical choices and to keep those choices out of public debate (Rosengren et al. 1975, Clarke 2002).

Perspective 2: Social Aspects are intrinsically Bound Up with Technical Aspects

For social science, there is a second possible way to address the issue of radioactive waste management, the approach taken by this project, trying to develop it and make it clearer, better usable in policy making. This approach differs from that previously described to the extent that, rather than affirming the division between technical and social aspects of the issue, it takes as the object of analysis the perpetual back-and-forth between 'technical' and 'social' aspects of the problem. This leads us to see it as essentially a *socio-technical* problem, in which social and technical aspects cannot be understood and treated as being separate but must be recognised as being linked, as the hyphenated term itself suggests, and in mutually influencing interaction. This shift in perspective also brings with it a different understanding of controversy and conflict: instead of viewing controversy over the implementation of technical projects as symptomatic of a 'social pathology' to be 'diagnosed' and 'cured', it can be viewed in a more positive light as constituting an informal societal assessment of these projects (Rip 1986). Controversy is not understood therefore as an 'obstacle' to the application of scientific rationality and to progress, but as something with the potential to stimulate further research and initiate a learning process, translating what are seen as 'social' aspects into technical features.

> *A socio-technical approach involves social sciences helping scientists and engineers to find a good technical translation of public concerns about radioactive waste facilities, and to identify what these concerns are.*

Science and technology continuously feed problems for which they try to provide answers. But technical experts do not have a monopoly on the formulation of problems; problems can be defined by specialists and non-specialists alike, even if it is expert definitions that typically prevail. Conflicts arising from the disposal of radioactive waste cannot therefore be reduced merely to conflicts of implementation: they challenge the technical choices, and sometimes the idea that there is only one choice in the matter; that is to say, the idea that geological disposal is a necessary and unavoidable solution. In the discussions that develop on the subject, especially at the local level, questions and claims emerge (such as those associated with reversibility in France, for example) that require a *technical translation* of societal demands and requirements and, therefore, provide fresh stimulus to the dynamics of research and innovation.

In this context the role of social science is to follow such processes and participate in their dynamics. It consists in explaining the speech of social actors and identifying technical issues that are located in their arguments. The aim is also to discuss and evaluate procedures able to facilitate the back-and-forth between the requirements that are expressed during local controversies and exploration of new technical solutions or revision of proposed solutions.

A socio-technical approach is above all therefore a question of *translation* (Callon 1986). Promoting this kind of approach involves social sciences helping scientists and engineers to find a good technical translation of public concerns about radioactive waste facilities, and to start by identifying what these concerns are.

2.2 A Socio-Technical Perspective on Radioactive Waste Management

The second of the two perspectives outlined in Section 2.1 is the basis of the approach adopted and advocated by the InSOTEC project as a way of understanding better the relationship between social and technical aspects of the radioactive waste management process and the challenges that are faced. We deliberately emphasise that it is a process, composed of a wide variety of interactions between human and 'non-human' (that is, all of the other material elements of the situation), in a variety of configurations, spread over space as well as time. However robust or stable such a configuration – or components of it – may seem to be at a certain point in space or time, reconfigurations are bound to occur due to changes in the socio-political or economic context, in the accumulated knowledge base, or in technology (for example developments in radioactive waste management or nuclear energy production, resulting in different waste streams). Although the origin of a reconfiguration in socio-technical relationships may be attributable to an inherently social situation, such as a change in political regime, or to a technical development, this does not mean that these can automatically be treated as separate issues. In order to understand the challenges of implementing a particular technology, one needs to take into consideration how technical solutions are constructed, how artefacts are developed, and where the boundaries are drawn (and by whom) between the technical object and the social meaning given to it.

This thinking is not new. As of the 1980's, Science and Technology Studies (STS) emerged as a new strand of social scientific research which considered the social world to be shaped or influenced just as much by the technology it develops and 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 & Wajcman 1985). Actions and decisions take place within what some STS researchers refer to as *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 & Law 1989: 78). In other words, beyond what might look like exclusively technical questions lie configurations or *assemblages* of humans and non-humans, subjects and objects, the social and the technical.[7] Technical artefacts consequently embody political visions of society and, at the same time, have consequences for the ways in which humans relate to each other and to their environment, so that artefacts can be said to have politics (Winner 1986) and even apparently mundane technologies may shape our behaviours and our choices (Latour 1992). Consequently, when actors modify and translate their interests, they simultaneously modify and translate the knowledge and technological artefacts they use, develop and believe in, as well as their identities as actors.

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That is why InSOTEC has approached the question of radioactive waste management and geological disposal as a socio-technical problem, to be understood using correspondingly hybrid or compound concepts such as socio-technical processes, socio-technical challenges and socio-technical combinations, rather than as consisting of technical aspects on the one side and social aspects on the other, or as being about a technical 'content' surrounded by a social 'context'. As was pointed out in the synthesis report of Work Package 1, an STS approach emphasises the non-deterministic character of socio-technical processes and the unpredictability of policy decisions (Landström & Bergmans 2012). When studying these processes, STS scholars (e.g. Latour 2004; Sarewitz 2004) are sensitive to variations in circumstances and therefore approach science and technology as articulated together with specific social configurations and practices. A process of technical innovation then becomes a socio-technical process, the outcome of which does not follow in a simple linear way from the technical knowledge, nor from the social decisions made, as unexpected effects emerge from social negotiations and material engagements, specific to time and place.

For many technologies, the relationship between the social and the technical 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 technology and several different models competed for social approval (Pinch & Bijker 1987). However, such stability is always temporal and technologies can also disappear (e.g. steam engines, cassette recorders, VCRs, or the supersonic Concorde passenger airplane) or, for a host of reasons, become 're-problematised', to use the concept developed in the synthesis report of Work Package 2 (Barthe, Sundqvist & Meyer 2014). Geological disposal, although commonly presented by the expert community as the best available technology today to deal with the long term management of higher-activity waste and spent nuclear fuel, is not completely stable; if not due to continued contestation, then at least because it has not yet been implemented. Furthermore, each national project is to some extent a "first of its kind" facility (Zuidema 2013) requiring further research and development along the path towards implementation and involving changes, from the relatively minor to potentially more fundamental changes, to the repository as a technical object. [8] As it stands today, therefore, deep geological disposal of higher-activity radioactive waste remains in many respects a hypothesis, and its functionality for achieving safety over the very long term has yet to be empirically demonstrated.

Before we develop our argument any further, it is important to note that although we have referred to the social and the technical as being strongly interconnected, we do not imply that technical artefacts cannot routinely be treated as being relatively separate from their social context. In practice, however, this only applies to technologies that have been stabilized and standardized. Such technologies have thus become relatively (and temporarily) independent of those who created them, and of the context in which they were created. At that point technologies can be (relatively) easily operated and maintained by anybody (in the case of a vacuum cleaner or toaster), or by anybody with a specific competence (in the case of a car or a printing press). Such standardised technologies can also be relatively easily transferred to a different setting. Nevertheless, the way they end up being used will differ (even if only marginally) depending on the setting, potentially leading to the form or function of the technology or its social meaning being re-negotiated or re-problematised (e.g. the toaster with wider slots to allow not only the English, but also the French to toast their bread). Similarly alterations may take place over time without calling the whole technological object itself into question, for instance if an increasing use calls for improved care of human health (e.g. the introduction of the safety belt, head-rest and airbag in cars). Typically, the less standardised a technology, and the more complex the setting, the more *entangled* it remains with its social context or origin. The term *entangled* may seem an odd phrase to use but has two senses that capture something of the complex nature of the relationship between the technical and the social: the first, from everyday language, is the sense of being intertwined and inextricably bound up together; the second, which draws loosely upon the meaning given to the term in quantum physics, refers to the relationship between two entities which even when apparently separated continue to display connectedness in that changes in one of them produce changes in the other.

Radioactive wastes are currently managed by applying relatively standardised technology. This does not mean there will not be any controversy possible, but it would seem fair to say that the current practices for safely managing various waste types for at least a few decades are not really questioned. Deep geological disposal is a different matter. Whilst one could perceive a geological disposal facility as a technology, one could also argue that geological disposal is a strategy encompassing a range of diverging technologies, some of them relatively standardised (e.g. certain waste handling techniques), and some of them highly innovative (e.g. wireless monitoring technology). One should therefore understand implementing geological disposal as an ongoing process of technological innovation (even if this technical innovation is limited by the frame of geological disposal) comprising social and technical aspects, with a strong entanglement and mutual influence between the two.

Through this notion of socio-technical entanglement we therefore aim to enhance awareness of the fact that although technical artefacts and social forces are routinely treated, for good reasons, as distinct and separate elements, in doing so what is very often forgotten is that they are intrinsically linked. We noted at the start of this section that we are advocating a more reflective approach which is more open to acknowledging complexity. We point to the value of this continued reflexivity for the long-term management of higher-activity radioactive waste (and/or spent nuclear fuel) in the conceptualisation of safety, in the development of appropriate technologies (including auxiliary technologies, such as those for repository monitoring), and in establishing and maintaining a relationship with the host community. In this last regard, it is of course inevitable that, in any country with a current nuclear programme, there is already at least one community hosting radioactive waste in one form or other. The waste problem is not therefore about introducing something new into society, but about how to handle something that is already ‘out there’. In addition to this easily observable ‘social aspect’, there is also the context of how nuclear programmes came about historically, and how they are perceived today. The proposed technology for dealing with the waste in the long-term cannot be seen separately from this context. Given the nature of the waste and the timeframes involved, implementing such technology is a long-term process in itself. The implications of the perspective and conceptual approach outlined in this section are developed further in Section 3, which applies them to a number of specific issues in order to draw out practical implications.

3. Taking a Socio-Technical Approach to Long-Term Radioactive Waste Management: Challenges and Opportunities

In this section we consider the extent to which the socio-technical approach proposed here could be supported when putting in place governance structures in the context of long term management of higher-activity radioactive waste, thus pursuing what in the research literature has been referred to as 'technical democracy' (Callon, Lascoumes & Barthe 2009).

During the second InSOTEC stakeholder seminar in November 2013, one of the central questions discussed was "What could or should be done to support a socio-technical approach in radioactive waste management?" (Schröder & Barbier 2013). Starting from the observation made in one of the presentations that the dominant view in modern society is that there is a clear divide between the social and the technical (Sundqvist et al. 2013), various issues that are relevant to attempts at overcoming this divide were raised by participants in plenary and working group discussions. They covered amongst others the following points: (1) The influence of disciplinary thinking and ways of working, including the challenges and problems associated with promoting inter- and transdisciplinary research in radioactive waste management; (2) The aspect of 'delegation', with an emphasis on the delegation of responsibility to technical or political experts; this raises questions as to the degree to which current approaches of public participation are suitable for overcoming delegation and strengthening co-production, and the distribution of roles and responsibilities among the different actors; (3) The need for long-term governance is one of the specific challenges facing radioactive waste management; this calls for flexibility and at least a minimum degree of openness in order to allow for developments in science and technology as well as in political and societal values and objectives, which means the technical and the social could not be easily stabilized as separate entities for a long time.

The country reports and case studies produced by Work Packages 1 and 2 of the InSOTEC project also reveal various problems raised by the unreflective separation of technical issues from so-called social processes. This can especially be observed in processes that are organised in distinct phases. Characteristics of such processes include efforts to confine discussions to specific topics within exactly defined timeframes or consecutive linear steps and restrictive framing of discourses on technological matters. Such efforts, although often based on good intentions (for example to achieve clarity of roles and transparency of processes), risk creating obstacles to technical democracy rather than fostering it.

Following the arguments presented in section 2, supporting technical democracy or a socio-technical approach in the long-term management of high-level radioactive waste should not be restricted to the question of siting, but should also include the development of the concerned technology. Therefore, when considering governance processes in this section, we explicitly start with the front-end, namely R&D into disposal technology, before moving on to implementation (esp. siting) and the question of long-term governance. However, there is no clear-cut boundary between these phases. They partially overlap and it would be too simplistic to approach them in a linear and consecutive fashion. However, some research that lays the basis for conceptualisation of a repository is obviously needed before one can contemplate implementation and it would equally be difficult to consider long-term governance without a view on implementation.

Section 3.10 draws on the analysis done by InSOTEC partners of the governance of R&D programmes, considering issues such as: Who sets the research agenda? (How) are boundaries drawn between technical research programmes and social sciences programmes? This section reflects on these findings, by arguing that the complex socio-technical issue of geological disposal cannot be properly addressed through a system that is focussing on compartmentalised scientific knowledge, and does not allow a continuous exchange between disciplines and between "technology and society".

The strong division of 'the technical' and 'the social' in R&D from the outset has consequences for the way research is undertaken by the different scientific disciplines involved and for the way the various publics might engage

Section 3.2 gives examples of the ways in which processes for planning and implementing geological disposal can either foster or hinder the adoption of a socio-technical point of view. To address this question, it focuses on conflicts, approaches to public participation and some characteristics of 'phasing' the process.

Section 3.3 elaborates on the characteristics of long-term governance in geological disposal. It underlines the need for flexibility in timing and technological solutions as a basic challenge for long-term governance processes. Considering the importance of timing, we analyse how this factor is on the one hand influenced by external events, such as political elections, and on the other hand presents a basic factor that shapes the governance process and thus influences its potential for dealing with the complexity of geological disposal. This section furthermore draws attention to the needs and approaches for facilitating learning among the involved actors as a basis for long-term governance.

3.1 Combining social and technical sciences for geological disposal

The development of R&D programmes in geological disposal in Europe often follows an approach consisting of dividing ‘the technical’ and ‘the social’. Implementers, responsible for managing R&D programmes for radioactive waste management in their countries, typically run a ‘technical’ R&D programme. However, in some countries they are also responsible for research on social aspects which is either organised in separate programmes (e.g. SKB’s social science research programme, 2004-2010, Sweden) or which may be integrated in one programme of technical and social issues (the approach chosen for instance by Andra in France). In some countries, implementers run the ‘technical’ R&D programme whilst other organisations (e.g. the Swiss Federal Office of Energy in Switzerland) are responsible for R&D on the ‘social’ aspects. Apart from the programmes of the implementer, in some countries, public bodies support specific research programmes in geological disposal or radioactive waste management. For instance, in Finland and France, the Ministry of Employment and the Economy and French National Centre for Scientific Research (CNRS), respectively, lead R&D programmes to promote and encourage scientific work in diverse disciplines in this field, addressing also issues that go beyond the mere implementation of geological disposal.

The role of social sciences in R&D programmes reviewed within the InSOTEC project has usually been that of understanding public resistance to technical projects or decisions, without questioning the nature of the technical solution (Bergmans & Schröder 2012). The strong division of ‘the technical’ and ‘the social’ in R&D from the outset has consequences on the way research is being undertaken by the different scientific disciplines involved and on the way the various publics might engage in specific decision-making processes. The currently dominant approach makes it difficult to address radioactive waste management as a ‘socio-technical’ problem. Hence, the research environment lacks opportunities to facilitate the interaction between the requirements expressed during local controversies and the exploration of new technical solutions (e.g. long-term storage) or revision of proposed solutions (e.g. provisions for reversibility and retrievability). Thus, what is explained through the notion of technical problematisation in the synthesis report of Work Package 2 (Barthe, Sundqvist & Meyer 2014), is nearly absent in the research context.

InSOTEC proposes an approach that demands – from the different actors involved, i.e. not only implementers and regulators, but also researchers, policy-makers and other concerned groups in society, such as NGO's or local residents – adaptation to new roles, continuous reflection on values, expectations and mutual adjustment and refinement of potential solutions. The complex 'socio-technical' problem of radioactive waste management cannot be solved through a system of compartmentalised scientific knowledge and rigid disciplinary perspectives. The challenge is to convey information, which comes from science and society, allowing a plurality of values and understandings.

A backbone of R&D programmes on long-term radioactive waste management thus should be the consideration of interdisciplinary approaches. Nevertheless, interdisciplinarity does not occur automatically by bringing several disciplines together. In practice, some of the so-called interdisciplinary programmes are in fact multidisciplinary, where the different disciplines work in parallel rather than in an integrated way. This would seem just as much the case between various disciplines belonging to the 'hard sciences', as between the 'hard' and the social sciences. A good example of the latter is the way in which the social sciences are often reduced to mere communication and public opinion studies, particularly in Central and Eastern European countries, as shown in Deliverable 3.2 (Martell & Van Berendoncks 2014). Even in countries where there are research programmes that are defined and set up as interdisciplinary or including social science programmes on geological disposal, the two programmes are usually kept separate from each other.

There are multiple barriers to the development of interdisciplinary research programmes, ranging from different methodological approaches, the failure to recognise the value of other disciplines, to reasons that lie in the broader institutional context of the research environment. In specific cases, attempts are made to allow interdisciplinary interactions, particularly between social sciences and hard sciences through working together to discuss problem definition, methodology or scientific quality like in the recently launched interdisciplinary "ENTRIA"[9] research project in Germany. Furthermore, there are still tensions regarding the definition of the problem and the relationship between social and technical knowledge. As a result, rather than interdisciplinary, what is achieved in most cases is a network of researchers from different disciplines undertaking different research projects under a common national R&D programme.

Furthermore, stakeholder involvement in the development of R&D programmes on geological disposal in Europe is rather limited. The agenda-setting phase and the review of R&D results provide tremendous opportunities for collaboration between different types of knowledge and for bridging the gap between problem-solving and innovation. However, engaging science and society and articulating different types of knowledge in jointly framing the problem is not easy. From language and communication problems to the legitimacy of research results, there are multiple challenges to such collaborative (also referred to as transdisciplinary) forms of research. A recurring barrier to cooperation between different disciplines and stakeholders in the field of radioactive waste management is the lack of common understanding of key terms and definitions. The concerned actors, no matter if they are participating, financing or reviewing collaborative research projects, therefore have to be aware that it is imperative to invest time and resources in defining concepts such as risk from a transdisciplinary perspective.

3.2 Engaging public and stakeholders with geological disposal

Governance of geological disposal is a complex process, characterised and influenced, among others, by the distribution of roles and responsibilities among the involved players and their interaction, the competences in and ways of decision-making, the defined procedural steps, the technical regulations and the mechanisms and considerations relating to public participation. This all is embedded in the political and regulatory system, in national traditions, in the history of nuclear power and waste management, and so on, in short, in the national context specific to each country.

This section neither aims at being exhaustive with regard to governance-related factors of geological disposal nor does it claim to provide concrete advice on how to shape governance processes under specific conditions. It rather focuses on two issues identified by InSOTEC research as relevant to our discussion on how the consideration of the socio-technical interrelationship in geological disposal is either fostered or hindered: dealing with conflict, and phasing the implementation processes.

Dealing with Conflict

Conflicts between different actors in geological disposal, especially between the public and the implementer or the regulator exist in more or less each country that has to deal with radioactive waste. Conflicts may relate not only to technical solutions, but also to procedural or political issues.

In recent years, processes for public participation seem to have concentrated on avoiding conflicts and shaping environments that foster interaction and co-operation (see, for example, the references to various national approaches in FSC (2010)). While striving for interaction and co-operation is seen by the proponents of such initiatives as being self-evidently desirable, they are too often framed by notions of 'reasonable' dialogue, consensus and agreement which at best may be idealistic, in the sense that they do not reflect the realities of these interactions and relationships, and at worst may exclude actors who will not conform to the terms of discourse that this imposes (see, for example: Gunder 2003, Sanders 1997). At the same time, some countries have adopted a so-called 'voluntary approach', which gives potential host-communities the right to apply voluntarily to participate in a siting process. Such approaches may foster an attitude - and a culture - of avoiding or – as fast as possible – solving potential conflicts, rather than accepting them "*as a driving force for the achievement of a better understanding of differences and agreements in the matter and its assessment*", as the German Committee on a Site Selection Procedure for Repository Sites put it in its final recommendations (AkEnd 2002: 50). At least two suggestions for overcoming an often rather negative approach towards conflict can be derived from the InSOTEC research.

One way of harnessing rather than avoiding conflict is to recognise that striving for absolute consensus can become counterproductive when it suppresses stakeholders' critical attention and defers clarification of critical issues of disagreement. Instead a critical review of the project by the stakeholders and the general public should be encouraged, and an attitude of 'healthy distrust' from these groups should be welcomed, both within and outside formalised participatory processes.

...striving for absolute consensus can become counterproductive when it suppresses stakeholders' critical attention

The early developments of the Asse research mine - as it was called during its operational phase - in Germany provide a striking example of how a lack or a neglect of critical attention can influence the safety of a disposal project (Kallenbach-Herbert 2013). The decision by the federal government in the 1960s to use the Asse salt mine as a research facility for disposal of low- and intermediate level waste found at the time broad support in the political, scientific and nuclear industry circles. The common interest of demonstrating a solution for the management of radioactive waste left no room for critical questions. Furthermore, a competent supervisory authority for an (independent) review of nuclear safety had not been installed as the project was implemented under the mining law – not under atomic energy law. These circumstances shaped an environment where warnings on the geological unsuitability of the Asse mine which had been articulated by members of the regional public had been neglected.

Our second example highlights the limits of what could be called 'invited participation'. There is indeed a widely shared tendency to talk about public participation only in cases of various forms of invited participation, when implementers, state representatives and public participation professionals carefully organise public dialogues and other 'democratic experiments'[10]. What (and who) is excluded from such activities is considered as a question outside of the democratic process. This is particularly true for protest and conflict, which are often regarded as something alternative to and even incompatible with democratic public engagement. A telling example of this is the turning point in the Czech siting case, when the implementer tried to start a new, 'democratic' phase of the process, open to dialogue with stakeholders, in 2009. An international conference was organised, the first of its kind in the country, entitled "Towards geological disposal without conflict". It is symptomatic that this conference was, in fact, an attempt to get out of a deadlocked situation (moratorium) caused by the previous technocratic approach and subsequent conflict (Konopásek & Svačina 2014: 11). A formal dialogue, organised "top-down", was launched as a direct consequence of a conflict, and designed to prevent conflict.

Democracy is the art of living with, not without conflict.

But what else is a protest or conflict than a primary form of democratic public participation? What else is it than a natural expression of citizens' interests in public issues related to their communities? Democracy is the art of living with, not without conflict. The current tendency towards elaborated forms of invited participation turns this principle upside down. It contributes to the exclusion of active stakeholders from the process (see also discussion about IGD-TP and who is to be included: Martell & Bergmans 2012: 45), and prevents (both formally and informally) participants from being engaged outside the formalised dialogue[11]. In doing so, it isolates its participants from real-life politics (sometimes intentionally, such as in the case of RISCOM as applied in the Czech Republic, designed as an artificial space for dialogical experiment[12]). It furthermore contributes to framing the siting process as a 'social' phase, separate from the rest of the process, with the aim to prepare ground for subsequent purely 'technical' implementation. Indeed, mistaking "lab-participation" for democracy typically implies the view that only certain phases of the process need to be democratic, i.e. that there is a special moment for democracy.

This tendency to promote lab-participation exercises over spontaneous political engagement of the public is not specific to geological disposal, but the tendency seems particularly strong in this field. It not only compromises the legitimacy of the proposed technical solution, but it also harms our current political environment, to the cultures of democracy of our highly technologised societies.

Phasing the Process

The widely adopted 'stepwise' approach to geological disposal aims to separate a long and complex process into smaller steps, (see section 3.3). This is of course reasonable, as it allows to structure actions and to make complexity manageable[13].

However, from a socio-technical perspective this approach may be somewhat double-edged as it bears the risk of 'phasing' the process in a way that may (unintentionally) lead to separating 'social phases' from 'technical' ones, 'preparatory' or 'research' phases from the 'implementing' ones. This happens especially in situations when negotiations break down due to 'social' resistance against 'technical' implementation. Purifying the social from the technical (or vice versa) occurs easily when the two domains are separated in time, when a certain level of technical development is taken for granted and left aside until a social consensus is achieved. This was precisely the favourite and often repeated formula of the Czech implementer, which helped to rearticulate the process of siting as essentially a 'social' problem. A similar formula was used in Finland, when it was argued that disposal of Fennovoima's spent nuclear fuel was not a problem that needs to be solved today and that there was, in fact, plenty of time to deal with the question (Konopásek 2014; Kojo & Oksa 2014).

An exaggerated separation of different phases has two main implications:

- The consideration of public opinions, contributions and concerns is limited to a certain phase of the process aiming at a consensus that, once achieved will last "forever", neglecting societal developments that clearly preclude such long-term agreements.

- Societal influence on technical questions is reduced to selected issues, at the most to those that are defined to be relevant for the specific phase. Public discussions on preceding and subsequent developments in planning and implementation do not take place.

The latter implication is not only a matter of separation but also of a hierarchical ordering that is a natural consequence of structuring a complex issue into manageable steps. The question of what shall be done at which step and in which detail can help prioritising research, development and planning efforts. But adopting a socio-technical perspective implies recognising that different priorities and stakeholders' requirements might emerge over time. They have to be considered if a meaningful exchange with stakeholders and the public shall take place and thus desire openness and flexibility of the governance process.

In short, a phased or stepwise approach has to be planned and implemented so as to not compromise the sensitivity towards complexity (and socio-technical entanglement) of a geological disposal project as a whole and to ensure a meaningful integration of social demands in technical developments.

3.3 Characteristics of Long-Term Governance for Geological Disposal

The notion of time is crucial when considering the development and implementation of geological disposal within a frame of technical democracy. Adaptations to unforeseen changes in the social and natural environment, as well as technical innovations, demand flexibility and openness to new requirements at different levels. At the same time, decisions need to be made and objectives set, in order to be able to move towards possible solutions. Reconciling the competing demands for adaptability and goal-centeredness is one of the main challenges of long-term socio-technical decisions and of adequate governance of respective processes. To address these competing challenges of flexibility, openness and goal-centeredness calls for the capacity to learn as a key element of management processes.

Reconciling the competing demands for adaptability and goal-centeredness is one of the main challenges of long-term socio-technical decisions and of adequate governance…

Taking a step beyond stepwise representations of the process

Common representations of geological disposal of high-level radioactive waste convey the siting and implementation process as a stepwise approach. Further detailing of the process is often illustrated as stepwise progression through technical decision-making based on scientific criteria for siting (Figure 1).

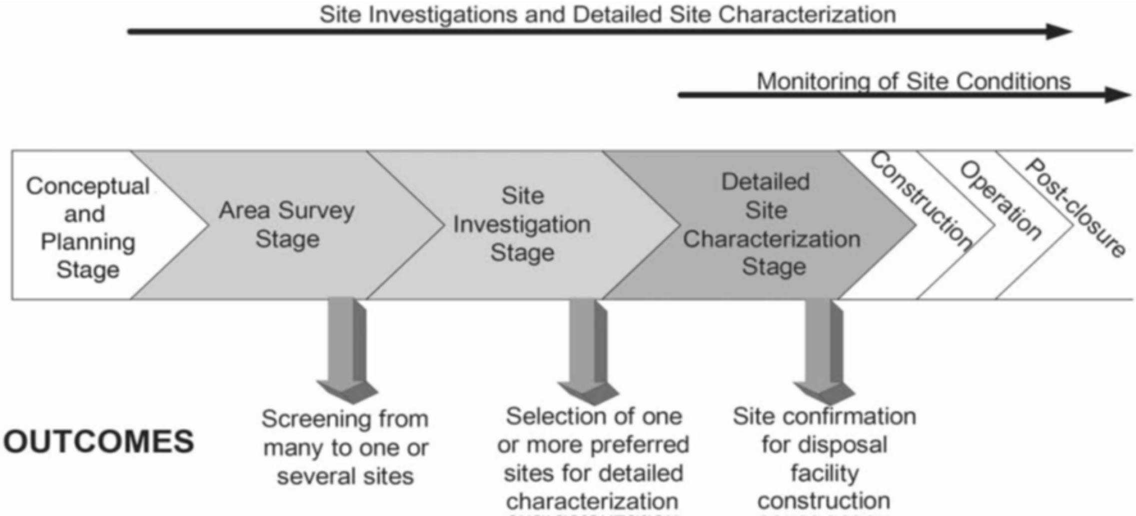
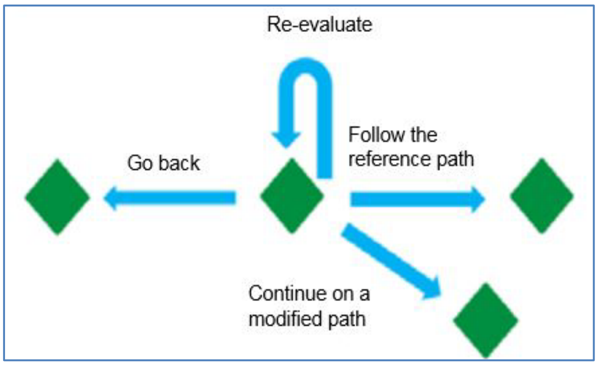


Figure 1: *Stages in the development and implementation of geological disposal, with the emphasis on the siting process,* IAEA (2011)

In such representations, the process is symbolically represented as a continuous linear movement.

It was the discussion on retrievability and reversibility (R&R) that in recent years brought some movement into this linearity (Figures 2 and 3). Even if internationally no common understanding could be established, yet, there seems to be a general agreement that the notion of retrievability implies the possibility of iteration or stepping back in an implementation process if new knowledge makes this necessary, or, as the NEA puts it: “Reversibility implies a willingness to question previous decisions and a culture that encourages such a questioning attitude” (NEA 2011). The graphical representations used by the NEA and Andra symbolise the four potential outcomes of interim assessments during the disposal process. They also reflect the recognition that learning and innovation processes are not linear; they call for side paths, reiterations, etc. This has especially to be kept in mind in view of the long time-frames associated with the implementation of geological disposal.



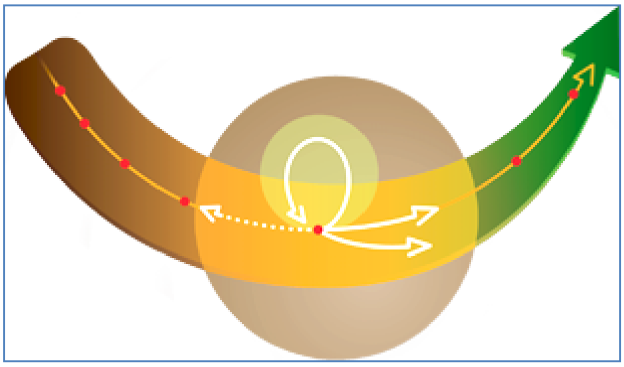


Figure.2: Potential outcomes of option assessments including reversal (NEA 2011)

Figure 3: Reversibility &retrievability diagram (Andra)

More detailed reflections on the role of retrievability and reversibility as a socio-technical challenge can be found in the InSOTEC topical report (Schröder & Bergmans 2014) and the respective case studies cited there.

A general difficulty in graphically representing the timescales of geological disposal is the fact that the timeframes for implementing geological disposal exceed those of any ordinary industrial project. Building a nuclear power plant, for example, may take a decade (as the case of Olkiluoto 3 demonstrates[14]) and the operational lifetime of some of the existing reactors can be four decades[15]. But this amounts to only half of the time estimated for 'pre-closure' activity in many of the most advanced (and thus most concretely estimated) geological disposal projects, which one needs to consider a timeframe of at least 100 years, as the following quote from Posiva (2014) shows:

> *"The first preparations for final disposal already began in the 1980s. In 2000, the Olkiluoto island in Eurajoki was selected as the site for final disposal. The construction licence application for the repository was submitted in 2012 and the operation licence application in 2020. The final disposal is scheduled to start in 2022. According to current plans, the final disposal would end in 2112 and the repository would be sealed up by 2120."*

This is, of course, under the assumption that no major deviation of this proposed schedule arises. However, the longer the timeframe the greater will be the potential for deviation. When we consider the historical timeline, nearly fifty years have passed between geological disposal featuring for the first time in 1957 as a formally proposed solution by the US National Academy of Science (NAS 1957) and the "decision in principle" for the repository in Olkiluoto that was ratified by the Finnish Parliament in 2001. A licence application for the construction of the concrete facility was submitted by Posiva in 2012. The Swedish implementer SKB applied for a license in 2011. As the above quote shows, the further implementation and operation is to take at least another century. Over such an extended period of time, a changing socio-political and economic environment as well as evolution of techno-scientific knowledge will be inevitable and governance processes will have to be able to face such evolutions. Given the inability to demonstrate the long-term safety of the facility 'upfront' and in practice (due to the long timeframes), we suggest to approach geological disposal as an on-going socio-technical experiment, in the sense of an open-ended exploration (Landström & Bergmans 2014).

Governing the Long-Term

When addressing geological disposal as an on-going, and for the time being open-ended exploration into the safe long-term management of high-level and long-lived radioactive waste, it becomes unproductive to delineate governance processes in time, or link them to specific steps or phases, such as siting. Siting is not the end-point in the negotiations between the waste management system and society. It is when 'hosting' starts (Landström & Bergmans 2014), when the most affected groups and communities are identified and the project becomes more tangible. The transition from siting to hosting may bring the focus to the local level, to the host community or communities. However, it still implies a long-term process that will transform both society and the technology as it proceeds, and which calls for flexibility and reflective governance processes that provide the concerned communities the opportunity for active engagement not only in preselected but in any issues of the project they deem relevant.

For a local community the hosting of a geological repository requires new institutions that can satisfy demands for democratic decision-making and public engagement, as well as technical safety and economic viability. It is not enough to engage local publics in the distribution of community benefits and then let the experts work out the design and management of a facility. The local community in its diverse manifestations, ranging from elected local authorities to concerned residents, to unwavering opponents, will want to be involved, not only informed. Critically, it is the local community that can provide continuity over the decades that the implementation takes, but it is also the group that is most personally affected by this activity and thus the entity having a direct interest in processes of technical democracy.

Taking local co-production seriously draws attention to the integration of geological disposal with existing political orders. This could mean reconsidering the way in which decisions are made – and communicated to the public. Conceived of as a techno-scientific process, geological disposal entails the idea of closure through consensus, derived from the vision of decision-making being based on rational debate about optimal solutions. However, geological disposal is a long-term activity, problems addressed at one time may very well resurface at a later date, and awareness of this has to be built into the decision-making framework. One aspect of local co-production is the on-going review and adaptation of the process itself to changing circumstances. Co-production is demanding, challenging and slow, but it can move forward in conditions in which reliance on rational consensus would risk paralysing the process.

Promoting Flexibility and Learning

In this last section, we aim to make more tangible the previous insistence on flexibility and keeping alive the process of innovation, even within processes that are inevitably coloured by some form of path-dependency. In line with our normative stance that the democratic process must prevail in developing and implementing a new technology, we take the position that for technical democracy to have meaning all of those actors concerned with the issue should have a responsibility to participate in the ongoing process of co-production.

A first recommendation is for practitioners – be it a local politician, a regulatory body or an implementer – to acknowledge uncertainties and complexity and also to acknowledge that the timescale of planning and implementation of a repository depends not only on the availability of technical solutions but also has to deal with changing values, new knowledge, societal and political requirements and so on. Furthermore, there is a need for new institutional structures and common foresight activities whose activities are not constrained by electoral cycles.

A second recommendation is to incorporate more visionary, open thinking – from the conceptualisation of the technology through to its implementation. Arguably the most widely used timelines with regard to the implementation of geological disposal are defined by means of 'backcasting' from the desired technical end point of final closure. In view of the approach proposed in this report, one of open-ended exploration, there is a need for forecasting that can deal with different societal and technical needs. In this regard, it is necessary to stop taking the long term as an excuse not to focus on society today. Different types of scenario-building techniques can be used to support this but the process of scenario development itself, as noted by researchers reviewing their use in other fields of socio-technical change, needs to be open and transparent (McDowall and Eames 2006). Participatory approaches, used increasingly in innovation and sustainability planning, will also be important to facilitate social learning and to ensure that adequate account is taken of context, timing and the requirements of specific actor groups involved (Johnson et al 2012). Nevertheless, some decisions will inevitably have to be passed on to future generations, and we need to recognise the limitations in the extent to which the present generation can make plans for generations to follow.

A long-term governance process faces specific challenges with regard to the preservation of various types of relevant knowledge over time, e.g. on the types and location of waste, geological and chemical parameters of the repository, methods and results of long-term safety assessments. For this reason, records and different tools of knowledge and memory preservation have to be built up. This kind of documentation is needed for recording technical developments and adjustments, and the related social and political evolutions and decisions. It also allows the disclosure of information and an integrated as well as institutionalized learning over time (Brohmann 2014; Sendzimir et al. 2006). The challenge of preserving knowledge, records and societal memory – not merely preserving the physical integrity of artefacts but also preserving the meaning of their content - over the very long timescales involved in geological disposal is the focus of continuing deliberation by the expert community (NEA 2014). In the short to medium term, however, steps could be taken toward developing knowledge and record systems that facilitate both greater openness and institutional and societal learning. For example, an 'issue register' that captures events and issues of importance, be they considered techno-scientific or socio-political in nature, could be developed using a well-structured and monitored open source device (such as a wiki platform) which facilitates documenting and tracking the innovation process over time.[16]

Innovative management elements, such as the application of assessment tools, the adaptation of (technical) solutions by iteration, the implementation of learning steps, and institutionalised monitoring, may be considered as possible elements in an adequate set of management tools for long-term governance. Although the development of management tools was beyond the scope of this project, models and schools of thought exist which might provide a framework for more reflective and flexible approaches to long-term governance. Two examples of approaches currently being deployed to manage long-term processes of socio-technical change – Transition Management and Adaptive Management - will serve to illustrate the strategies available to help deal with the tension between short-term decision pressures and long-term thinking.

Transition Management (TM) is an approach that has been developed in light of long-term transformation processes towards sustainability and is generally described as "forward looking, adaptive and multi-actor governance" (Kemp & Loorbach 2006). The TM model includes seven key elements which illustrate the conditions and prerequisites of a flexible management process that includes multiple actors at different levels, offers a framework for at least 25 years under which short-term policies take place, deals with uncertainties by using participative processes for scenario-building and follows a "learning-by-doing approach. The TM approach is currently being used to govern the transition to a low-carbon energy system (the *Energiewende*) in Germany.

Adaptive Management (AM) was developed in the late 1970s (Holling 1978) and provides a structured approach aimed at continuously improving management actions through learning from the outcomes of such actions. AM involves iterative cycles of six consecutive phases (assessment, designing interventions, implementing interventions, monitoring, evaluation, adjustment), with each new set of actions tested in the next cycle. This last feature is referred to as 'management experimentation' (Walters 1997). Applications (e.g. in relation to forestry, fishery and river systems) indicate that AM processes can enhance the prospects for reducing key uncertainties and effectively achieving desired objectives (Walters 1986; Gunderson and Holling 2002; Sendzimir et al. 2006).

Neither these examples nor any other model should be rigidly applied, of course, but should be approached with the same open-minded and reflective attitude that we have proposed for the technology of geological disposal. Nevertheless they provide already developed – and still developing – frameworks which could be adapted to the specific challenges of long-term radioactive waste management.

4. Conclusions

The InSOTEC project addressed the issue of the long-term management of long-lived and higher-activity radioactive waste by studying and describing the processes of implementing geological disposal as the proposed technology, while aiming to avoid often made assumptions of inherent differences between social and technical aspects of such processes. Instead, InSOTEC encourages thinking differently about the relationships between social and technical aspects of the radioactive waste management process. We see this process as composed of a broad variety of interactions between humans and non-humans, in various constellations, spread out over space as well as over time. However robust or stable such a process may seem at a certain point in space or time, reconfigurations are bound to occur due to changes in the socio-political or economic context, in the accumulated knowledge base, in technical development, etc.

Therefore, one should understand implementing geological disposal as an on-going process of technological innovation (even if this technical innovation is limited by the frame of geological disposal) comprising social and technical aspects, with a strong mutual interaction. While this is generally acknowledged by most parties concerned, there remains of a strong tendency of separating technical artefacts and social forces as distinct elements. While such separation has good reasons, it (too) often contributes to the neglect of the intrinsic links between the two. What is advocated here is therefore a more reflective (realistic, flexible, subtle) way of considering 'the technical' and 'the social' in the long-term management of higher activity wastes, by acknowledging complexity, rather than pretending to reduce it.

There is no single – or simple – solution that will provide a problem-free way of approaching long-term radioactive waste management. The following summary of findings is offered, however, as a contribution to shaping the processes in a way that pays more attention to the interrelationships between social and technical aspects, acknowledges complexity and the need for openness, with the aim of cultivating a more reflective, realistic and resilient process.

Going a step beyond stepwise

In the context of implementing geological disposal we find various models that divide the long and complex process into smaller steps in order to make it manageable within the framework of established (or proposed) governance procedures. However, what seems perfectly reasonable from the point of view of an implementer or a decision maker wishing to reduce the number of issues that require a solution at any one time by taking things step by step, can become an obstacle to reflecting adequately on the close interrelationship between technical and social aspects, what was referred to in Section 2 as the 'entangled' socio-technical nature of the problem. This may arise because public participation is restricted to selected parts of the process or, less explicitly, because technical issues are in large part excluded from discussions involving the public: this may be, as is often the case, the result of a lack of active promotion of public debate on technical issues or it may be the result of the terms of reference or framing of the debate, which can lead, whether intentionally or unintentionally, to such discussion being closed down.

Recognising the need for participation beyond organised forms

When public participation in long-term radioactive waste management takes place, it is typically in a form of invited and organised dialogue. However such a format risks excluding parts of the public and preventing them from contributing to the development of the proposed technology. This does not mean that forms of organised participation, e.g. via representatives of different societal groups, may not be a reasonable tool, but the democratic process should neither be limited to participation of a selected group under a defined framework, nor should it be reduced to a certain phase of a planning and implementation process. This should especially be considered by those institutions that are responsible for defining the procedural framework and by those responsible for leading the process (or of certain parts of it), be it the regulator, the implementer or any other organisation.

Changing the approach to conflict

In a democracy, controversies and conflicts are a normal part of how people pursue and defend their interests. In a democratic process of implementing long-term management strategies for higher activity wastes, conflicts are inevitable and can have effects, such as delayed or deferred decisions or escalating costs, that are seen by many of the parties involved as being negative and undesirable. However, conflicts should not only be understood in negative terms. Although conflict is often interpreted as being due to a lack of knowledge or to misunderstanding, reflecting the so-called 'deficit model' of public (mis)understanding of scientific and technological issues (Irwin and Wynne 1996), it can also be seen as an informal assessment of the problem definition and of the proposed technical solution. From this perspective, conflict can be useful, as it may allow proponents to recognise weaknesses of the proposed technology and to make adjustments. So, although conflict may be experienced in the short term as an unwelcome and ungovernable disruption, it can constitute an opportunity to learn and to improve a technical project in ways that may make it more broadly acceptable.

Taking advantage of this opportunity means organising a learning process that can lead to re-problematising, in the sense discussed in Section 2, at least some of the technical features of the project; in other words to opening up to scrutiny and debate technological commitments that conventional decision-making processes may be designed to close down (Stirling 2008). Such a process would need to be organised with a long-term perspective and thus comprise procedures for capturing problems raised in different arenas and for translating them into new R&D questions. Although identifying ways in which this might be implemented is beyond the scope of this report, one concrete example could be for waste management organisations to set aside a proportion of their research budget to respond to questions that the public indicate they would like researched. Although this may seem a radical proposition, it is similar in some respects to the idea of 'citizen budgets', where municipalities set aside a part of their budget for projects suggested by citizens.[17]

Embracing flexibility and avoiding technological 'lock-in'

To facilitate learning, the geological disposal project as a long-term management strategy should be flexible, that is to say it should remain open to change, adaptation and correction. The notion of reversibility could be useful in organising such flexibility. This vision of what we could call an experimental or open-ended process is of particular relevance when faced with the time-scales associated with the nature of the waste as well as with the implementation of any long-term management strategy. Considering these timescales it is perfectly conceivable that at present we are not able to envisage all problems, changes in the context, etc. that could arise over time.

This calls for a different approach to dealing with uncertainties. We therefore propose approaching the implementation of geological disposal as a (scientifically) controlled, open-ended exploration towards a possible solution. Flexibility thus also means the ability to maintain the capacity for technical innovation, which implies the continuation of research programmes as an integral part of the implementation process. This may have implications in terms of costs, but on the other hand allows for a more realistic implementation of an inevitably long and still-developing process, taking several generations to accomplish. A classical project-based approach, with a clear beginning and end-point does not work in this situation.

To be useful not only for the development but also for the societal acceptability of the technology that is being developed and applied, both the implementation and accompanying research programmes should seek to engage society at large, and the most directly concerned actors in particular, in defining what are the remaining questions and how they should be addressed. This could be the responsibility of the regulator, a public administration or a dedicated oversight committee, and take the form of milestone ‘meeting points’, not just to inform a diversity of stakeholders on the current state of affairs, but also to collect new questions or revisit old ones. In this perspective, we can also imagine going further and setting up structures for ‘community-based research’, as one can find in the area of public health, where concerned groups (e.g. patient associations) are invited to discuss and contribute to the design of research programmes.

Overcoming disciplinary barriers

This last suggestion brings us back to the argument presented earlier, that the complex socio-technical problem of geological disposal cannot be solved through a system of compartmentalised scientific knowledge. Despite growing recognition of the potential value of taking an interdisciplinary approach to complex problems, however, existing institutional research frameworks often make it difficult to foster such approaches. Nevertheless, engaging in problem-oriented research and development of this kind has been shown to be a particularly strong stimulus to overcoming the barriers to working across disciplines and this is something that is consonant with the discourse at least of national and international institutions, which provides an opportunity structure within which this can be actively pursued by the relevant R&D communities. More challenging to current ways of thinking and working is the notion of *trans*disciplinary research; research that provides opportunities for meaningful involvement of stakeholders. Although some have questioned whether this can genuinely be achieved, examples documented in the research literature suggest that, given the necessary conditions, it can; they also suggest that the potential benefits to all parties make the experiment of trying to achieve it worthwhile. This would require not only the willingness of research institutions and individual researchers to venture beyond the frontiers of their own disciplines in order to address complex questions of societal relevance, but also the willingness of stakeholders and citizens to engage in a sustained manner with the technical problems and repertoires of the R&D communities. We see three opportunities for addressing this challenge:

- Include social science research as an integral part of, rather than a mere adjunct to, conventional techno-scientific analysis in R&D programmes on geological disposal.

- Exploit the opportunities provided by the agenda-setting phase and the review of R&D results for fostering collaboration between different types of knowledge.
- Establish – or adapt existing – independent expert bodies or dedicated oversight committees to link researchers, industry, policymakers and civil society in collaborative research processes tailored to address scientific and societal changes in innovative ways.

This concern with the production of knowledge and of the socio-technical strategies and solutions required to address the problems posed by long-lived higher-activity radioactive waste brings together, therefore, the different strands of the InSOTEC project. The insights and recommendations summarised in this report derive from an analytical perspective that emphasises the *necessity* of viewing the problem posed by geological disposal as being fundamentally *socio-technical* in nature. The use of the term proposed here contrasts to the still-superficial way in which this now-widespread phrase is typically used in the field of radioactive waste management. InSOTEC has highlighted the implications of this perspective not only for governance processes but also, importantly, for research and development. In doing so it has challenged the conventional division of research into technical and social aspects of the problem and, further, the division between experts and 'non-experts' when determining the nature of the problems to be addressed and developing effective, resilient and societally-acceptable solutions.

Notes

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

[3] The materials designated for geological disposal vary according to national policy and the specific technologies employed in the nuclear energy sector and may include, for example, spent nuclear fuel, high-level wastes from fuel reprocessing, and long-lived higher-activity intermediate level wastes. For ease of reference the generic phrase "higher-activity wastes" is used in this report.

[4] The Deliverable synthesis reports produced by the other InSOTEC work packages contain a fuller account of the themes presented here, with individual national and case study reports providing a further layer of detail. InSOTEC reports, working papers and presentations are currently available from the project website: http://www.insotec.eu/.

[5] Throughout the report there are occasions where terms that might appear to be quite straightforward, such as 'technical' and 'social' are presented, as here, in single quotation marks. This slightly intrusive practice is used to indicate that the terms in question, despite being commonly used, are problematic or at least that they need to be treated with caution. This is most often because, as with this particular pair of terms, they are seen as taken-for-granted categories which mask or pass over important aspects of the thing or process to which they refer. Alternatively it may be because the meaning of the term is different for different actors or in different contexts and therefore subject to multiple interpretations or is even, in a more fundamental sense, a contested concept (Gallie 1956).

[6] Even where public reactions appear extreme to the implementers of technological projects, they can usually be shown to be rational in terms of a different framing of the situation and of a correspondingly situated or context-specific rationality.

[7] The logic of this becomes apparent when one considers the argument that not only must anything technological have a human and thus a social origin (cf. Bijker et al. 1987), but also that society itself would not be possible without technological artefacts and infrastructures. What may have begun with the manufacture of basic implements created from stone, iron and bronze has evolved to produce and support the complex and interdependent societies in which we live today; societies which can neither exist nor be understood apart from their equally complex technical systems for energy and food production and distribution, for sanitation, for human mobility, for economic exchange, for knowledge production and dissemination, for communication, for shelter, etc. Technical objects and systems are the basis not only for social interaction and social organisation, but also for the production of social value and of social identity. The technological and the social are not therefore separate yet somehow inseparable elements of our world but, properly considered, cannot *exist* independently of one another, which brings into question the technical/social distinction itself.

[8] Zuidema refers to repository construction as *to some extent* a 'first of its kind' project because there are three examples of existing geological repositories. Two are former salt mines in Germany, neither of them engineered in the first place specifically for the purpose of radioactive waste disposal; both of them have displayed signs of structural instability requiring active intervention. The third is the US Government's purpose-built Waste Isolation Pilot Plant, located in New Mexico, emplaces packaged transuranic wastes in chambers excavated 650 metres below the surface in bedded salt rock. However, the designs of national repositories will differ according to, for example, the host rock selected, the nature of the wastes to be deposited, and any regulatory requirements for reversibility and/or retrievability of the waste.

[9] The ENTRIA project 'Entsorgungsoptionen für radioaktive Reststoffe: Interdisziplinäre Analysen und Entwicklung von Bewertungsgrundlagen' is a five years research project that comprises 12 German and one Swiss research institutions and several academic disciplines. It aims at fostering the integration of technical and non-technical sciences and the development of scientific know-how in the radioactive waste management context.

[10] Bogner (2012: 510) calls such efforts "lab-participation" and writes about paradoxical effects of it. He defines lab-participation as "a form of participation organised by professional participation specialists, taking place under controlled conditions and largely without reference to public controversies, political participation demands, or individual concerns".

[11] The participants in the Czech dialogue group accused each other of acting outside of the formal space of the group, indicating that it is a kind of betrayal of the entire dialogic effort. Some mayors noted that their participation in the group led toward decreasing informal contacts between them – in fact, the Group for Dialogue effectively depoliticized the siting process (See InSOTEC working papers Konopásek & Svačina 2014 and Konopásek, Soneryd & Svačina 2014).

[12] On the RISCOM model and its application in Sweden and the Czech Republic see the InSOTEC WP 2 working paper (Konopásek, Soneryd & Svačina 2014: 8).

[13] On the stepwise approach to decision-making, see FSC (2004).

[14] In July 2014, twelve years after the decision in principle to build a third reactor unit at Olkiluoto power plant, and exactly nine years after the start of construction and first concrete pouring, due to repeated delays the new plant had still not been delivered. It is now estimated that construction of Olkiluoto 3 will be completed in mid-2015, which would put back full operation to 2018-2020 (AREVA 2014).

[15] Olkiluoto 1, to stay in the logic of the Finnish example, was connected to the grid in September 1979, following a five-year construction period (IAEA 2014).

[16] Documentary issues registers have been published in the UK both by the national waste management organisation, the Nuclear Decommissioning Authority (NDA), and by critics of geological disposal, Nuclear Waste Advisory Associates. See: Nuclear Waste Advisory Associates (NWAA) Issues Register March 2010 http://www.nuclearwasteadvisory.co.uk/uploads/11569NWAAISSUESREGISTER[Version1.1].pdf and NDA (2012), which includes in the appended issues register its responses to issues raised by NWAA. The NDA has also produced a searchable online issues register, albeit not one that is interactive or open to direct input by others: http://www.nda.gov.uk/rwm/issues/.

[17] Because of the growing popularity of this practice, specific online support tools have been developed. See for example: http://participedia.net/en/cases/citizen-budget

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