Monitoring the Safe Disposal of Radioactive Waste: a Combined Technical and Socio-Political Activity

DELIVERABLE (D1.3.1)

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Reporting period: 01/05/2009 – 31/12/2010

Date of issue of this report : **30/10/2012**

Start date of project : **01/05/2009** Duration : 54 Months

Project co-funded by the European Commission under the Seventh Euratom Framework Programme for Nuclear Research &Training Activities (2007-2011)		
Dissemination Level		
PU	Public	√
RE	Restricted to a group specified by the partners of the MoDeRn project	
CO	Confidential, only for the partners of the MoDeRn project	

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Executive Summary

1. Introduction

The purpose of this report is to provide a basis for stakeholder engagement activities in relation to the monitoring of facilities for the geological disposal of radioactive waste. The report views monitoring as a combined socio-technical activity central to the pursuit of safe repository operation and staged closure. It sees monitoring for long-term safety as a field driven as much by social and institutional innovation as by technical innovation. The report is organised into three main sections which discuss in turn: expert views on monitoring, drawing on interview and documentary data; the role of monitoring in building stakeholder confidence, drawing on experience in other contexts; and monitoring as a socio-technical activity, focusing on the basis for social trust.

2. Expert Views on Monitoring

The investigation of expert views of monitoring drew on two sources of data: key international technical documents and interviews with 18 experts (mainly technical specialists) from radioactive waste management and research organisations.

For the experts interviewed, monitoring is about collecting information on the repository system, mainly for purposes of decision-making. More specifically, it is about observing through measurements the behaviour and impact of the repository system. For the technical partners in the MoDeRn project the focus is on confirming that repositories will perform as required and that the basic safety assumptions are correct. In addition, however, assurance and confidence building were mentioned by all respondents as being one of the main drivers for monitoring. Three distinct aspects of this role of monitoring were identified:

1. Monitoring to assure the implementer
2. Monitoring to assure the regulator
3. Monitoring to reassure the public and build confidence in the repository

Most experts interviewed had not yet explicitly discussed monitoring strategies with local stakeholders. Many therefore found it difficult to anticipate what lay stakeholder expectations of monitoring might be and whether it would be technically feasible to meet them. Several respondents expressed the view that local stakeholders were likely to be more interested in environmental rather than near field monitoring, and in post-closure rather than operational monitoring.

The technical specialists saw post-closure monitoring to provide additional assurance of post-closure safety, particularly if this were to involve monitoring of internal or near-field processes, as a major challenge. Developing the tools and techniques necessary for such monitoring was considered by many of our respondents to be more a question of R&D than of engineering and implementing an already available solution.

Two elements are crucial here. The first is that of reconciling the need to monitor processes within the repository with the principle of passive safety by developing non-intrusive monitoring techniques. Therefore many respondents explicitly referred to post-closure in situ monitoring as unrealistic and potentially counterproductive. In addition to answering the question of *how* to monitor safely, however, there is also continuing discussion about *what* should be measured, i.e. which specific processes – or parameters that, in the relatively short period before closure, would provide data conclusive enough to accurately predict future system behaviour. This has both implications for post-closure and pre-closure monitoring. The general position taken by the experts interviewed, was that it will be possible to identify measurable parameters that would enable them to validate (and if need be adjust) the models on which they build their safety cases, but only a very few.

3. Stakeholders, Monitoring and Confidence

A review of literature on citizen and stakeholder engagement with monitoring identified examples from the nuclear sector and from other contexts that offer useful insights into stakeholder concerns, institutional arrangements and monitoring practices, as well as drawing out implications for stakeholder confidence.

Most of the activities reported involve some sort of *environmental* monitoring. Furthermore, although there is evidence of a variety of modes of organisation of monitoring, one important feature was the extent to which a *participatory* approach has been adopted. This aspect is singled out in the report because it is consistent with the turn to collaborative or partnership-based approaches, involving the active engagement of stakeholders, which has been adopted by radioactive waste management programmes in many countries, typically as a response to lack of stakeholder trust in implementing organisations or confidence in the safety of geological disposal.

The review found many examples of environmental monitoring commissioned or conducted by local institutional stakeholders, particularly local government, including some examples that integrate this with monitoring of the socioeconomic environment. There are also several examples from the USA of monitoring for radiological contamination following known releases due to nuclear weapons testing, as well as the accident at the Three Mile Island nuclear power plant. Dissatisfaction with or distrust of institutions has also led members of some communities to demand or even initiate participatory environmental monitoring. In the field of radioactive waste and other nuclear industry facilities, there is considerable evidence of stakeholder and citizen involvement in monitoring activities. Although they are for the most part not associated with geological disposal facilities they point to the desire of citizens and communities in many different contexts for active engagement with monitoring programmes.

The examples discussed, although drawn from varied contexts, tend to report positive effects of such involvement for stakeholders, typically local citizens and community organisations, and for their relationships with experts, regulators and decision makers. Reported outcomes include increased confidence in programmes, operators, regulators and scientific experts, and the added value of enhanced social capital and community capacities, although not all of these could be shown to have resulted in all contexts. Nevertheless it is important to be cautious about the potential outcomes of such engagement programmes in light of the well-documented challenges of participation.

4. Monitoring: a Combined Technical and Social Activity

It is clear from our research that the expert community recognises monitoring to have both technical and social purposes. While there are strong technical reasons for monitoring a geological repository, questions of evidence, confidence and decision-making always have, to a greater or lesser extent, a social component.

The prevailing paradigm for geological disposal today is one of continuous vigilance. This is by and large a matter of social preference: a result of how society today interprets nuclear safety. The technical act of monitoring and the way its results are given meaning then become an important instrument in the pursuit of vigilance. This is particularly the case for nuclear installations such as power plants, fuel production or reprocessing plants, and storage facilities. Deep geological repositories, in their inherent reliance on passive safety, can be understood as a way of trying to renegotiate the need for tireless vigilance. The question is then how to interpret this need for surveillance: How much vigilance is enough and how should it be organised? This is a societal question that cannot be answered from a technical-expert perspective alone.

Lay stakeholder views on what monitoring can and should contribute to long-term safety of a repository are likely to differ to those of experts, due to fundamentally different views on what it means to stay vigilant and for how long. This is because society at large may not be as confident as the expert community that it is possible to ensure (safe) long term repository behaviour. These doubts arise for many reasons, but are at least partially based on known cases of institutional and technological failure. Another reason is the concern that some risk will remain due to the impossibility of foreseeing all contingencies; yet expert statements on repository safety that do not acknowledge such uncertainties may not be perceived as trustworthy.

The concept of trust is important in understanding the underlying mechanisms on how monitoring may or may not contribute to building confidence in geological disposal. Given the imperceptible nature of radiation citizens have little choice but to rely on experts and expert systems to ensure their safety. However, Eurobarometer surveys reveal considerable national variation in attitudes towards scientists and experts, with citizens in many countries displaying public ambivalence and even overt distrust towards the institutions that employ them.

Cultivating good personal relationships can contribute to establishing and maintaining a degree of trust between individuals who interact regularly but this has limitations when considering whole institutions and large groups of stakeholders. The alternative to interpersonal trust is to establish mechanisms that underwrite trust in the (impersonal) activities of institutions; in the case of a radioactive waste repository this may include giving specific consideration to roles and responsibilities with regard to monitoring, to creating transparency and to maintaining vigilance.

For society to decide how much vigilance is needed and for how long will require confidence in the repository system and trust in those responsible for designing, implementing, overseeing and regulating it. It may be easier for social actors to commit to the successive stages of concept development, siting, licensing, construction and operation, if the provisional nature of their trust is acknowledged and there is at each stage the opportunity to evaluate and reconsider their commitment.

Monitoring can also help to demonstrate that the operator of the disposal programme is aware that there are uncertainties involved and is willing to take appropriate precautions. The risk associated with such openness is that it may appear to bring into question the premise of passive safety as the technical solution to the societal problem of vigilance engendered by higher activity radioactive wastes. By introducing the notion of retrievability or reversibility into law, however, some countries are already moving towards an adapted sociotechnical solution: one that still relies on achieving passive safety, but which recognises that this end point may be further away than initially planned and, subject to future societal decisions, may not be final. Such evolutions remind us that we will inevitably pass the burden of decision about final closure to subsequent generations. Acknowledging this requires that we think more specifically about the type of information, knowledge and skills that need to be passed on to future generations, and the role that monitoring might play in meeting the needs of future operators, regulators, decision-makers and affected citizens.

5. Concluding Observations

The exploratory stakeholder engagement exercises planned in the next phase of this research will build upon this review and are intended to supplement the inferences, reported above, that we have drawn from the research literature. In this final section we consider the implications of our findings so far for engaging different types of stakeholders, in particular lay stakeholders, in defining monitoring objectives and strategies, and offer five observations.

First, monitoring is not an end in itself but part of a bigger story: it is intended to support implementation of geological disposal but this may entail it being put to quite different uses. Second, the way in which people view monitoring and what they expect to obtain from it differs according to (among other things) their attitudes towards geological disposal and the basis for long-term safety. Monitoring could therefore be part of the answer to the societal expectation that in order to ensure safety vigilance should be maintained. Third, this does not mean however that such issues need to be settled now and fixed for the duration of the disposal process. What seems important is that monitoring programmes are designed so that they remain flexible enough to respond to changing social and regulatory expectations. Fourth, the process of monitoring should be transparent and open to public and expert scrutiny. This will have to be built into the institutional context through which roles and responsibilities for long-term radioactive waste management are organised. Finally, we conclude from our research to date that a more fully socialised concept of trust is central to understanding the extent to which monitoring may contribute to building confidence in geological disposal.

In conclusion we suggest that monitoring programmes in the context of radioactive waste management may well be able to contribute to public and stakeholder confidence, but that this requires that we recognize monitoring as a socio-technical activity that will involve the pursuit of social and institutional innovations as much as technical and industrial innovation.

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1 Introduction

This report is the product of research activity within the EC Seventh Framework Programme “Monitoring Developments for Safe Repository Operation and Staged Closure” (MoDeRn) Project. This project aims to further develop the understanding of the role of monitoring in staged implementation of geological disposal to a level of description that is closer to the actual implementation of monitoring.

MoDeRn’s view on monitoring is that it provides operators and other stakeholders with in-situ data on repository evolutions, to help manage construction, operation and/or closure activities, and may allow for a comparison with prior safety assessments. The project focuses on monitoring conducted to confirm the basis of the long term safety case and on monitoring conducted to inform on options available to manage the stepwise disposal process from construction to closure (including e.g. the option of waste retrieval). It thus provides information to inform necessary decisions. If, in addition, monitoring activities respond to stakeholder needs and provide them with understandable results, they will contribute to transparency and possibly to stakeholder confidence in the disposal process.

The project is structured into six work packages (WPs). The first four WPs are dedicated to (i) analyse key objectives and propose viable strategies, based on both technical and stakeholder considerations; to (ii) establish the state of the art and provide technical developments to match specific repository requirements; to (iii) conduct in-situ monitoring demonstration experiments using innovative techniques; and to (iv) conduct a case study of monitoring and its integration into staged disposal, including specific scenario analysis aimed at providing guidance on how to handle and communicate monitoring results, in particular when these provide “unexpected” information. The fifth WP regroups all dissemination and outreach activities and the sixth WP is dedicated to consolidating project results into a reference framework on how monitoring may be conducted at the various phases of the disposal process.

This report is to be situated within WP1 and addresses those elements that the authors see key when considering options for stakeholder engagement in developing monitoring objectives and strategies.

1.1 Why this Report?

The purpose of this report is to provide a basis for potential stakeholder engagement activity in relation to monitoring of facilities for geological disposal.

In the presentation of the MoDeRn project, monitoring is affirmed as of central importance to the successful implementation of a repository programme for radioactive waste. On the one hand, monitoring is seen as an essential practice, or set of practices, for confirming the technical safety and engineering quality of any such programme. On the other hand, it is asserted to be a vital tool for 'public communication, contributing to public understanding of, and confidence in repository behaviour' (MoDeRn 2009).

In this report the ambition is to investigate further monitoring as a collection of practices of combined technical and social significance in radioactive waste management, and to do so from a social science perspective. The advantage of adopting a social science perspective, it will be argued, is that this allows for greater appreciation of repository monitoring as a field driven as much by social and institutional innovation, as technical and industrial innovation. Monitoring can imply a range of different activities and arrangements introduced for a range of different purposes. Expectations on monitoring will differ between groups in society, and not uncommonly between individuals belonging to the same group or organisation. Monitoring, therefore, is not solely about the further development and calibration of measuring devices confirming repository performance. It is also a field where developing safety principles can be translated into practical arrangements, leading to their progressive institutionalization. Therefore, the setting up of monitoring programmes involves re-evaluating and re-enacting how safe repository operation and closure should proceed, as well as the distribution of roles and responsibilities in the socio-technical decision process.

Therefore, rather than focussing on solely the practical organizational challenges of setting up stakeholder engagement with monitoring conceived as an exclusively technical activity, this report will promote an appreciation of monitoring as a combined socio-technical activity central to the pursuit of safe repository operation and staged closure. Key issues to be addressed in this report from a combined socio-technical perspective are: What is the underlying logic and rationale for the monitoring of a geological disposal facility? What meaning is ascribed to the monitoring of geological disposal by different actors, and in particular expert stakeholders? At what stages of repository development is monitoring considered most relevant and indispensable, and how is it planned to implement programmes? What are the limits of monitoring activity? How can monitoring as an activity dedicated to producing new forms of visibility be reconciled with the principle of passive safety informing geological disposal and the total isolation of radioactive waste from the biosphere?

This report represents the authors' reflections on repository monitoring and the role envisioned for it in radioactive waste management, based on their participation in the MoDeRn project and through their interaction with technical experts in this emerging field. It describes points of interest and discussion identified by the authors that could form the basis for meaningful interaction between experts and a broader range of interested parties and stakeholders on monitoring issues.

Given the stage of development of geological disposal programmes in most countries participating in the MoDeRn project, the focus of this report is primarily on the potential for engagement with (lay) stakeholders in the earlier stages of repository development (i.e. before actual construction and operation of a facility) and the integration of monitoring activities into the repository concept. However, due attention will also be given to the role of different concerned actors in monitoring throughout the repository development and closure process.

1.2 Basis for this Report

This report draws on two forms of source material, the first being empirical data from a variety of sources and the second being relevant research literature on public and stakeholder relationships to monitoring, particularly in the context of nuclear facilities.

The data that has been collected (between September 2009 and November 2011) and analysed includes:

- Recordings of interviews with experts (mainly technical specialists) associated with the MoDeRn consortium;
- Observational and recorded data collected through participation in project and other workshops on geological repository monitoring or related issues;
- Technical documents including internal project reports and reports by other bodies;
- Documents that record stakeholder views on repository monitoring and related issues.

Face-to-face interviews were conducted with a number of MoDeRn consortium members and some of their technical colleagues. Between January and July 2010 in all 18 representatives of waste management agencies or their technical partners were interviewed. The majority of these were technical experts, most focussing on the issue of monitoring within their organisation. Three respondents had a social sciences or communications background and particular expertise with questions of stakeholder engagement. The open, semi-structured interviews focussed on: the respondents personal views on monitoring objectives; on what they assumed other stakeholders' views and how to incorporate them; on how to communicate about monitoring results; on how to handle unexpected results; on their views on post-closure monitoring; on their personal experience with lay stakeholder involvement and expectations from lay stakeholder involvement for developing a monitoring programme. All interviews were recorded and transcribed. In Section 2 of the report quotations taken from the recorded interviews are used to illustrate key findings. Names of sources are not reported for reasons of privacy, nor is their affiliation, unless this was considered relevant to understand the context of the quote in question. A list of experts interviewed is appended to this report.

1.3 Structure of the Report

In Section 2 the report examines the different meanings that are given to monitoring in the context of the geological disposal of radioactive waste and considers where, in that respect, the focus of the MoDeRn project lies. It summarises the views and interpretations on the subject offered by experts and found in technical documents, including understandings of the purpose and design of monitoring programmes, and of the process of putting them into practice. In addition, expert perceptions of stakeholder concerns and their expectations of broader stakeholder engagement activities dealing with monitoring are discussed. In Section 3 what is known from published sources about citizen and stakeholder concerns and expectations of repository monitoring is reviewed. Given the relatively limited incidence of such monitoring, citizen involvement in other, more or less comparable, forms of monitoring is also reviewed. In Section 4 the material presented in the two earlier sections is compared and analysed from a social science perspective, paying attention to the inherent dual nature of monitoring as a combined technical and social activity, and considering how monitoring in relation to geological disposal could be perceived and approached from the perspective of non-technical stakeholders, including affected citizens. Finally, in Section 5, we conclude by discussing and summarizing the practical implications of addressing monitoring as a combined socio-technical activity.

2 Expert Views on Monitoring

In this section we take a closer look at what technical specialists in the field consider to be the role of monitoring in relation to the geological disposal of radioactive waste. We look at expert definitions of monitoring and the purposes assigned to it; the different approaches and types of monitoring being proposed and developed, as well as the needs and opportunities identified by experts for bringing in different stakeholder perspectives to help shape monitoring strategies.

Throughout this section of the report, we attempt to 'follow the actors' (in this case the technical expert community) so as to try and understand their thinking and give meaning to their actions. We will not analyse monitoring strategies as ready-made entities, but rather attempt to follow the reasoning of 'the best of all guides - scientists and engineers themselves' (Latour 1987) along the paths they are currently taking to build these strategies. We shall do this by referring to strategic and technical documents on monitoring produced by national agencies or international organisations or in project settings; to interviews with experts from different waste management agencies represented in the MoDeRn consortium; as well as to observations from workshops organised by the MoDeRn consortium or others in relation to the subject of monitoring for geological disposal. Cultivating the perspective of the curious outsider we shall reflect over and attempt to summarize what we have learnt from following the experts.

The structural integration of monitoring activities in the geological disposal process appears to have become more widespread over the last decade. The report of a European Thematic Network on this subject offers three reasons for this (EC 2004). First, geological disposal itself has only within that same timeframe evolved from a paper and laboratory concept to a more concrete and implementable project, and still only realistically in a handful of countries. Secondly, as national programmes develop towards more detailed site investigations and implementation, the stepwise nature of implementation, entailing a sequence of stages, has become more apparent, as has the 'need for well-founded decision bases and evidence (to which monitoring will contribute)'. Furthermore, with projects becoming more concrete and more visible to the public and to potentially affected populations, issues of (public) confidence have come to the fore (NEA 1999). This has given rise to a need to verify and confirm repository performance by monitoring repository processes in order to enable future decision-makers to judge at each stage the appropriateness of taking the next step in implementation, right up to final closure of a facility.

In the meantime, defining and carrying out a monitoring strategy has been listed as a Safety Requirement[1] for the geological disposal of radioactive waste by the IAEA in 2006. With these safety requirements, the IAEA wishes to set 'protection objectives and criteria for geological disposal' and to establish 'the requirements to ensure the radiological safety … during the operational period and especially in the post-closure period' (IAEA 2006). Operational controls, monitoring and testing are seen as essential for assuring operational safety. They are seen as contributing to the further development of the post-closure aspects of the safety case during the period the repository remains operational, and are considered to provide baseline information for taking decisions on the closure of the facility. However, it is stressed that 'safety is ensured by passive means inherent in the characteristics of the site and the facility and those of the waste packages' (IAEA 2006: 4). Monitoring and institutional controls are therefore not considered a requirement to ensure post-closure safety. Nevertheless, a potential role in providing assurance is recognised for post-closure monitoring and institutional controls, particularly in relation to maintaining nuclear safeguards and to measures contributing to 'social acceptability' (IAEA 2006).

Although monitoring had been referred to in several documents before, with the presentation of these safety requirements, monitoring is explicitly recognised by the IAEA as playing an integral part in assuring the safety of a geological repository. In this respect, three specific requirements concerning monitoring programmes have been formulated by the IAEA:

> *"A programme of monitoring shall be defined and carried out prior to and during the construction and operation of a geological disposal facility. This programme shall be designed to collect and update the information needed to confirm the conditions necessary for the safety of workers and members of the public and the protection of the environment during the operation of the facility, and to confirm the absence of any conditions that could reduce the post-closure safety of the facility."*
>
> *"Monitoring is carried out during each step of the development and operation of the geological disposal facility. The purposes of the monitoring programme include providing baseline information for subsequent assessments, assurance of operational safety and operability of the facility, and confirmation that conditions are consistent with post-closure safety. Monitoring programmes are designed and implemented so as not to reduce the overall level of post-closure safety of the facility."*
>
> *"Plans for monitoring with the aim of providing assurance of post-closure safety are drawn up before construction of the geological disposal facility to indicate possible monitoring strategies, but remain flexible and, if necessary, will be revised and updated during the development and operation of the facility." (IAEA 2006: 31-32)*

[1] Safety Requirements are to be situated in between Safety Fundamentals, which set out broad objectives, concepts and principles, and Safety Guides, which offer recommendations and guidance on how to operate in practice. Safety Requirements are expressed as 'shall' statements. Not meeting them means measures will need to be taken to restore the required safety level (IAEA 2010).

This strengthens the impression that monitoring is here to stay and will need to be treated as an integral part of repository development and design. But an internationally recognised requirement or even obligation to monitor does not necessarily imply a shared understanding of what monitoring is and how it could and should be conducted, even if most of the experts we have encountered wholeheartedly subscribe to one and the same definition of monitoring for geological disposal as their point of reference.

2.1 The Experts' Reference Definition of Monitoring

The technical partners in the MoDeRn project consider the work of the European Thematic Network (ETN) on the role of monitoring in a phased approach to the geological disposal of radioactive waste (2001 - 2004)[2] as their point of reference. As the majority of experts interviewed also referred to the ETN definition of monitoring, we will start by looking more closely at this definition and suggested strategies relating to it. The ETN did not, however, operate in a void. Around the turn of the century, monitoring became a matter of concern, first in the world of implementers and waste management agencies, and soon after also among regulators and safety authorities. With plans becoming more concrete in different countries, the need to consider monitoring strategies and other forms of control became ever more apparent and frameworks were being explored for developing common understandings and goals, and setting international standards in this field.

Prior to the setting up of the ETN, work had been initiated on monitoring. The IAEA's Waste Technology Section for example had set itself the task of preparing a report in its TECDOC series[3] dedicated to the issue of monitoring for geological disposal. TECDOC-1208, issued in 2001, was based on a number of meetings held between December 1996 and February 2000, bringing together several technical experts, mainly from waste management agencies across the world.

Although monitoring of geological repositories had been referred to in earlier IAEA documents (e.g. IAEA, 1989; 1991), the first explicit definition of monitoring for geological disposal can be found in TECDOC-1208. Here monitoring, is defined as:

> *"continuous or periodic observations and measurements of engineering, environmental or radiological parameters, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment."* (IAEA 2001: 1).

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[2] Participants from 10 countries were involved, namely: Belgium, Czech Republic, Finland, France, Germany, The Netherlands, Spain, Sweden, Switzerland, and the UK.

[3] The IAEA Technical Documents (IAEA-TECDOC) report on various aspects of the Agency's work. They do not aim to set standards or guidelines, but are intended to contribute to on-going debate on specific topics.

Later the ETN extended the IAEA definition to encompass potentially any parameter deemed important to investigate, emphasising the role of monitoring in support of decision-making. Monitoring is thus defined as:

> *"continuous or periodic observations and measurements of engineering, environmental, radiological* ***or other parameters and indicators/characteristics****, to help evaluate the behaviour of components of the repository system, or the impacts of the repository and its operation on the environment,* ***and to help in making decisions on the implementation of successive phases of the disposal concept.****" (EC 2004: 10).*

So in short, **monitoring is about collecting information on the repository system**, ultimately to support decision-making. More specifically, it is about **observing through measurements** the behaviour and impact of the repository system. It is about **assisting in making visible what otherwise**, without the proper instrumentation and evaluation models to interpret the obtained data, **would remain invisible**.

Both definitions above can be read in relation to more general definitions of monitoring, as for example provided in the Oxford English Dictionary, where 'to monitor' is defined as:

> *"to check or regulate the technical quality of something without causing any interruption or disturbance; … to observe, supervise, or keep under review; to keep under observation; to measure or test at intervals, esp. for the purpose of regulation or control." (http://dictionary.oed.com/).*

From an outsider's perspective this seems reassuring, as it indicates that irregularities and unexpected events could be communicated to a lay audience. The ETN definition appears to explicitly suggest a three step process of (i) observing, (ii) making visible, and (iii) deciding.

However, the question remains how the expert community views the practical implementation of monitoring and whether this will be able to meet the expectations of other stakeholders. In the following paragraphs we will explore the commonalities and discrepancies that exist in technical expert representations of monitoring. The relation to stakeholder expectations, which will be explored in Section 3, will be further examined in Section 4.

2.2 Decision-Making and Confidence Building as Determinants of Monitoring

In both the IAEA TECDOC-1208 (IAEA 2001) and the ETN report (EC 2004) multiple reasons are given for why a geological disposal facility should be monitored. At second glance and with reference to what we have learned from interviews and discussions with MoDeRn consortium members, it appears appropriate to conclude that **monitoring is about seeking confirmation that the facility performs as required and that the basic safety assumptions were correct**. In this respect, the diversity of reasons given in the two basic reference documents can actually be subsumed under two broader categories – taking into account that both are, to a large extend intertwined:

1) monitoring to support decision-making, and
2) monitoring to provide (re)assurance.

A similar interpretation of the core reasons for monitoring is provided by ONDRAF/NIRAS when setting out its overarching strategy for the development of a testing and monitoring program for the Belgian geological disposal program:

> *"The current and primary objectives of the Belgian long-term testing and monitoring program are to (SNL - URS 2009: 6):*
> - *Confirm long-term repository performance, and*
> - *Assist in decision-making."*

For our report, we therefore focus on monitoring for purposes of (re)assurance, in addition to monitoring for purposes of decision-making, as the concepts of assurance and reassurance allow for the incorporation of the notion of performance confirmation, as well as of a number of related elements that we have come across in our analysis.

In the following paragraphs we will look more closely into both functions of monitoring.

2.2.1 Monitoring in Support of Decision-Making

Several of the reasons mentioned in the IAEA TECDOC-1208 [a] and ETN report [b] relate, directly or indirectly, to a **supporting role for monitoring in decision-making**:

- 'to support management decisions in view of the staged development of the repository programme' [a],
- 'to support societal decision-making on the major stages of the repository development programme' [a],
- 'to accumulate an environmental database for future decision-makers' [a], and
- 'to establish baseline conditions' [b].

Thinking about monitoring and its role in relation to geological disposal is strongly related to how a process of repository development is viewed. Even if the whole of the radioactive waste management community is dedicated to the eventual closure of any constructed geological repository, it is expected that reaching this stage will take at least several decades. The decision-making process for long-term radioactive waste management, including the development and implementation of a geological repository - as the final endpoint in the long-term management of particularly high-level waste and spent fuel - is generally recognised as demanding a stepwise approach (see e.g. NEA 2004a; NAS 2003). In such a stepwise progression towards the final goal of closure, monitoring is considered by experts to play an important role:

"In itself, monitoring is not indispensable for the safe operation of a repository, but it nevertheless has a specific role to play." (Respondent 5)

"… this fits with the recommendations of the NEA concerning progressive transition towards passive safety. We cannot let this transition happen abruptly. It has to happen progressively, and be demonstrated while doing." (Respondent 9)

"The whole system is conceived to rely on passive safety. Monitoring has to help us prepare and make that transition from active to passive" (Respondent 8)

"Monitoring is of particular importance in relation to progressive closure. To be able to decide to start closing a facility, one has to have at one's disposal the necessary measurements to take that decision. Monitoring is therefore a fundamental decision-making tool: both for the decision to close, as for the possibility to reopen. This works two ways. I don't think we will proceed towards closure if measurements would show any kind of anomalies." (Respondent 4)

The perceived role of monitoring as an aid to decision-making can be derived from the above quotes. Both in view of operational and management decisions (e.g. adopting a new technique for waste emplacement after several years of operation), as well as with regard to decisions concerning major steps in the process (e.g. decisions to start operations or to close the facility): the role of monitoring is to support decisions 'concerning the evolution and future development of the repository facility' (Respondent 6) and to provide both the implementer, the regulator and society at large with the confidence that a decision to close the facility can be taken. Monitoring plays this supportive role by 'verifying that the safety requirements are met, both during operations and in the long term' (Respondent 2).

This last distinction between operational safety and long-term safety is the key to understanding where the main challenges lie for developing monitoring strategies for geological disposal. We will come back to this in the following sections.

Obviously, there is a strong link between the role of monitoring in supporting decision-making and the second role experts attribute to it in providing (re)assurance. This second role, as we will demonstrate in the following paragraphs, however, goes further than supporting decisions and is, in this respect, even more fundamental.

2.2.2 Monitoring for (Re)assurance

Although not always easy to distinguish from decision-making, other reasons mentioned in the IAEA TECDOC-1208 [a] and ETN report [b] place emphasis on **monitoring as a means to provide assurance, or reassurance that the facility performs as required**:

- 'to check and ensure the safe operation of the repository' [a][b],
- 'to strengthen the understanding of system behaviour' [a], or
- 'to confirm key assumptions regarding the safety-related features of the disposal system' [b].

Both documents furthermore stipulate a role for monitoring in addressing the requirement of nuclear safeguards. This stipulates the assurance that 'no unlawful retrieval of material from the repository can take place' (EC 2004).

However, only once during our interviews was the issue of nuclear safeguards spontaneously raised by a respondent, and even then not as an immediate reason for monitoring. Only when explicitly asked, did others comment on the possible relationship between monitoring and nuclear safeguards. This may to some extent reflect the very specific focus of the research being carried out by many of our respondents. However, the view of some seemed to be that, because of the technical difficulties of retrieving waste from a closed deep geological facility and the unsuitability of the materials for weapon production, illegal recovery of waste for such purposes in the post-closure period was an improbable scenario, but that monitoring against such an eventuality could be achieved by satellite surveillance (see also EC 2004: 11):

> *" Anyone who is a nuclear engineer or a physicist will tell you that making atomic weapons out of spent nuclear fuel is such a nonsense, no sensible person on earth would do that."* (Respondent 10)

> *"From the moment everything is sealed off, all you need in terms of safeguards is some camera surveillance; and even that is frankly not necessary. Who would want to amuse himself by digging a hole several hundred meters deep in the ground before even reaching the waste? Such things will hardly go unnoticed."* (Respondent 2)

The issue of (re)assurance or confidence building on the other hand was explicitly and repeatedly mentioned by all respondents as one of the main drivers for monitoring:

> *"The biggest challenge is that we talk about projects extending over a period of several decades. It is therefore only logical that you apply monitoring to make sure your system performs as required; and this to give both lay people and experts the confidence that the repository is well managed. With respect to the safety authorities, monitoring can confirm for them that the licence they issued was rightfully granted and that all activity is in compliance with the conditions set in that licence."* (Respondent 7)

As is clearly expressed in the above quote, our respondents did not consider the role of monitoring in providing reassurance as limited to public confidence building. The primary motivation of monitoring for them is that it allows for self-assurance and of demonstration to the regulator that all is well and will most likely remain so. So let's have a closer look at this threefold role of monitoring to provide reassurance.

2.2.2.1 Monitoring as a means of assurance for the designer, modeller, implementer

> *"Before we used to think: 'Monitoring is something to convince others'. Now we think we should broaden the scope, so that it is also useful to us. Monitoring is necessary to confirm your design."* (Respondent 8)

> *"We think we know enough and that we are sure of ourselves, but it's always better to verify that. … We are talking here about an installation that is unique, and in that sense it is necessary to take monitoring one step further. This is what is behind our notion of monitoring. We may have a passive system in mind, but we*

do not have any real experience with that. So the best thing to do, is to observe as much as possible and to understand what happens down there." (Respondent 3)

Monitoring was viewed by many of the experts interviewed as an important verification tool. Two closely related but distinct aspects were referred to: verifying the repository system; and verifying the modelling behind it.

Performance confirmation, interpreted here in the broadest sense as checking if the repository behaves as it should, thus confirming that prior decisions were sound and that the basis for passive safety is adequate, was seen as one of the most important monitoring objectives:

> *"Monitoring is the whole system of verification and control, of measuring, which indicates if the **repository system behaves as anticipated**." (Respondent 2)*
>
> *"For me, monitoring is the following up over a period of several decades (throughout the operational period) the evolution of the physical and chemical processes that occur in the repository and to verify if these are **consistent with what our models predicted**." (Respondent 3)*

A similar interpretation is to be found in IAEA TECDOC-1566 addressing factors believed to affect public and political acceptance of geological disposal. When considering monitoring, it is argued that:

> *"Particularly in a first-of-a-kind undertaking, it is impossible to rule out miscalculations in the projections of **repository performance**. It may be prudent to establish means to identify this type of error." (IAEA 2007: 12)*

In addition, many of the experts interviewed also referred to monitoring as essential in confirming that the basis of the scientific models on which their safety cases are build, is correct. Rather than on the behaviour of the repository itself, the emphasis is here put on the soundness of the models predicting repository behaviour, both in the (relatively) short term of repository operations and in view of long-term repository performance, that is after closure of the facility.

> *"Monitoring is a tool to verify from a technical perspective if the engineers' **models and predictions** are indeed correct, or need to be improved." (Respondent 5)*
>
> *"The purpose of monitoring is performance confirmation to demonstrate that the **models and predictions** that we took as a starting point actually correspond with reality." (Respondent 9)*
>
> *"Meanwhile we are able to calculate and predict the behaviour* [of mining structures], *but we have some uncertainties in it and for that reason … we use monitoring in the operational phase of the mining structures to improve our **models**." (Respondent 12)*

This particular role of monitoring was also explicitly referred to by the ETN:

> *"Monitoring data will be used in scientific models of repository performance, partly to provide input data, partly to assess the performance of the models in predicting monitoring observations and partly to allow the models to be updated and refined. In this manner the scientific models of the site and of the repository can be validated, adapted and refined or rejected." (EC 2004:26)*

When putting forward monitoring as a means of reassuring the experts themselves, the emphasis is clearly on **monitoring during the phase of construction and operation**. During this period, there is still (some) flexibility to refine the models that are used to predict system performance and long-term safety. Furthermore, it is argued, it would still be relatively easy to take action if monitoring results were to lead to more drastic intervention (e.g. package retrieval). So within that period, the objective would be to monitor for operational safety, for environmental impact assessment, for nuclear safeguards, <u>and</u> for long-term safety assessments. Given this there would appear to be a general consensus and clarity of purpose among experts.

Post-closure monitoring, however, is not seen by these experts as adding anything to the scientific case that will already have been made for the long-term safety of the repository, without which closure would not have been consented. :

> *"From a purely technical point of view, there are few needs for monitoring the environment of a closed geological repository, as there will not be anything to measure. … Post-closure monitoring in terms of making sure nothing goes wrong is pointless and contributes to a negative image." (Respondent 1)*
>
> *"What action would you take after closure, knowing this would imply substantially greater difficulty of first (re)accessing the repository?"* (Respondent 7)

This concern, that rather than providing reassurance post-closure monitoring might lead stakeholders to interpret it as evidence of scientific uncertainty and perceptions that the repository was not safe, has been fairly common among technical experts although it has now been accepted that it may have a positive effect

Post-closure monitoring of an underground repository itself – so in situ monitoring – is furthermore seen by many as unrealistic and even potentially counterproductive:

> *"Well, I think so far, at least the consensus here currently is that there is no post closure performance confirmation that all this monitoring is during the operational phase, not post closure to make it technically reasonable. One thing we want to be prepared for is if somebody requests a post closure performance confirmation of a cell that's 500 metres down in the ground, inaccessible and so on. That we say is technically unrealistic and it doesn't serve a purpose because the evolutions, physical evolutions are virtually identical if we just put a seal in front of that thing and for the first one thousand years you don't see a difference. If you see what I mean". (Participant B at Madrid workshop discussion)*
>
> *"Disposal is not something that's supposed to be monitored over the long term. You can monitor and prove that it has been implemented successfully, according to certain criteria, there are quality considerations, but to do it post-closure to the time that canisters fail and material starts to come out is just, you know, it's just inconceivable." (Respondent 14)*

The main reason for this sceptical attitude, is that experts are certain that monitoring given the long time frame of the system's evolution – 'we are talking here about canisters that are designed not to be breached for thousands of years' (Respondent 14) – will not be able to provide confirmation of those factors that provide long term safety, as one will only be able to measure only very few parameters for a very short time.

Furthermore it is argued that 'it would not be realistic to expect monitoring programmes to be sustained for such long periods of time' (Respondent 18).

Nevertheless, many people interviewed think there may be a value in post-closure monitoring, even if it is mainly to reassure other actors such as neighbours (see Section 2.2.2.3), but, as with all monitoring of the repository system, only insofar as it would not be intrusive.

> *"In [my country] … we have to monitor every mine some decades after closure. And I kind of understand the people who say: okay if you have a mine you have to monitor it and a repository is a mine too … So for mining reasons we monitor it, but not for radiological safety reasons. That would not seem very transparent. And then I say: okay, if you have to monitor anyway, then you put just one more sensor in the shafts and look whether there is radioactivity in the ground water or something like that." (Respondent 12)*

> *"In our main facility, intrusive monitoring will not be allowed (certainly not near the waste). In fact it is not so much about the wires being there, but about that taking the wires out at some point may not affect repository safety. That is why we need to look at what will happen for example if we put a glass fibre through a seal. Can we retrieve that later?" (Respondent 13)*

> *"Monitoring will start during the operational life of the facility and then outside of the barrier system, in my opinion, it should be continued [after closure] … But outside of the barriers, not to affect the repository safety. … They always say: 'Yeah okay there will be nothing during that time' but you just have to show that there is nothing. And for that reason you must monitor it, but that also means measuring the background radioactivity on the sampling points at the earliest of times." (Respondent 12)*

This position was also found in technical opinion documents:

> *"Post closure monitoring may be carried out for the purpose of accumulating an environmental data base on the repository site and its surroundings that may be of use to future decision makers." …*
> *"Post closure monitoring may be used to strengthen understanding of some aspects of system behaviour used in developing the safety case for the repository and to allow further testing of models predicting those aspects." (IAEA 2002: 10)*[4]

The key element for experts as regards post-closure monitoring is that 'it should not be done within or inside the very barriers that ensure safety' and that 'monitoring [i.e. taking measurements] alone, and in particular in situ repository monitoring, does not suffice to judge long-term repository behaviour' (Respondent 14). Other elements from other sources, such as experiments, models, or natural analogues should also be considered (Harvey and White 2011).

[4] Conclusions from a specialists meeting held in Vienna, 18-22 June 2001, considering issues relating to safety standards for geological disposal. One session was dedicated entirely to (post-closure) monitoring and institutional control.

2.2.2.2 Monitoring to assure the regulator

Other than to acquire assurance or confirmation of repository performance and the basis for the models that support the safety case, monitoring is also seen as instrumental in showing compliance with legal and regulatory requirements.

> *"... monitoring would also be carried out ...:*
>
> *(1) to determine any radiological impacts of the operational disposal system (as with a nuclear installation, like a power plant) on the personnel and on the general population, in order* ***to comply with statutory and regulatory requirements****;*
>
> *(2) to determine non-radiological impacts on the environment surrounding the repository,* ***to comply with environmental regulatory requirements*** *(e.g. impacts of excavation and surface construction on local water supply rates and water quality);*
>
> *(3)* ***to ensure compliance with non-nuclear industrial safety requirements*** *for an underground facility (e.g. dust, gas, noise, etc.)." (IAEA 2001: 3)*

By doing this, the implementer demonstrates to the outside world that he has his repository under control. A crucial actor in judging whether monitoring results indeed corroborate such claims is the regulator.

> *"The reason for compliance monitoring during each of the stages of repository development is to provide proof that the implementation of the disposal concept is complying with the standards and criteria set by the applicable regulations and site licence. Compliance will in turn give assurance that these criteria for repository behaviour will continue to be met." (EC 2004: 21)*
>
> *"I think it is clear that the monitoring system would be designed according to what the regulator says." (Participant A at Madrid workshop discussion)*
>
> *"The test is that the regulator is satisfied with it as one criterion that indicates the implementer is doing a good job in putting in place the monitoring programme." (Participant B at Madrid workshop discussion)*
>
> *"Monitoring is a way to show the regulator and others that we have control over our system and are capable of acting upon what we observe, including adapting our monitoring programme." (Respondent 2)*

Assuring the regulator is also seen as important because of the intermediate position the regulator holds between the implementer and the public:

> *"Well, the local stakeholders will not trust the implementer but normally they will trust the regulatory authority. So, the important thing is that the design of the specification for the monitoring system is agreed with the regulator." (Participant A at Madrid workshop discussion)*

Monitoring for compliance and to assure the regulator was particularly referred to in view of **monitoring for operational safety and for environmental impact assessment**, when considering potential consequences of constructing and operating a repository facility[5]. For these aspects, regulatory requirements are generally known today, and come from different regulatory authorities, such as mining authorities or nuclear safety authorities:

[5] As discussed for example during an internal MoDeRn workshop on monitoring objectives, held in Amsterdam on 1 September 2010 at which 10 experts were present.

“Where the operational phase is concerned, we are certain that there will be monitoring and that it will be necessary to monitor. … Existing regulation obliges us to provide for specific measures (e.g. radioprotection, …). This we already know today.” (Respondent 1)

“Regulatory boundary conditions that we need to take into account when developing our monitoring strategy are set by our mining regulations, regulations on radiation protection, workplace related health and safety regulations, and so on.” (Respondent 2)

But regulatory requirements for monitoring are also expected to comprise issues of **monitoring in view of making predictions on long-term** (or post-closure) **safety**:

*“The purposes of the monitoring programme include … confirmation that conditions are consistent with post-closure safety.” … “Plans for monitoring with the aim of providing assurance of post-*closure safety *are drawn up before construction …” (IAEA 2006: 32).*

More specifically in Finland, the radiation and nuclear safety authority, STUK, has recently issued draft guidelines for the planned geological repository, in which, with respect to monitoring the issue of long-term safety demonstration is explicitly raised and a minimum of objectives are set:

“During the construction and operation of the disposal facility, an investigation, testing and monitoring program shall be executed to ensure the suitability for disposal of the rock to be excavated, to determine safety relevant characteristics of the host rock and ***to ensure long-term performance of barriers****. This program shall include at least:*

- *characterization of the rock volumes intended to be excavated*
- *monitoring of rock stresses, movements and deformations in rock surrounding the waste emplacement rooms*
- *hydrogeological monitoring of rock surrounding the waste emplacement rooms*
- *monitoring of groundwater chemistry at the disposal site*
- *monitoring of the behaviour of engineered barriers.”* [6]

In Switzerland, the Nuclear Energy Act (KEG)[7] and resulting Nuclear Energy Ordinance (KEV)[8] stipulate a monitoring period, set by the authorities, and the construction of a pilot section of the disposal facility for the specific purpose of extensive monitoring of all components of the facility. This pilot section must fulfil a number of regulatory requirements, including the emplacement of a ‘small, but representative quantity of waste’ (KEV: Article 66).

In most countries, furthermore, some form of socio-political or at least regulatory decision is anticipated before the step to final closure of the facility will be taken. In France for example, it is stated explicitly by law that only a law could authorise the closure of a geological repository :

[6] STUK 2010: Draft YVL-guides - D.5 – 510: p.8 (https://ohjeisto.stuk.fi/YVL/D.5-L4.pdf - free translation from Finnish provided by Posiva).

[7] Kernergiegesetz, vom 21. März 2003 (KEG).

[8] Kernenergieverordnung vom 10. Dezember 2004 (KEV).

"… sa fermeture définitive. Seule une loi peut autoriser celle-ci" (Loi n°2006-739 du 28 juin 2006 de programme relative à la gestion durable de matières et déchets radioactifs: Article 12).

Similarly, the Swiss Nuclear Energy Act gives the Federal Council the authority to decide on the closure of the repository:

"Upon expiry of the monitoring period, the Federal Council shall order the closure of the repository, if the permanent protection of human beings and the environment is ensured" (KEG: Article 39§2).

Monitoring in view of predictions of long-term safety is in this respect considered of vital importance to support a decision (in one form or other) to close the facility.

"Not too long ago they used to think that the safety of an underground repository could be guaranteed in such a way that obtaining a licence would be proof in itself that it were feasible. … But thinking has evolved, also due to regulation, which is now so that a licence will not be issued once and for all, and that at least an extensive debate will have to take place before we could proceed with closing our repository. Therefore we need a continuous evaluation of performance throughout the period prior to closure, so that we can demonstrate that it works and that a decision to close the facility could actually be taken with confidence. So the need to confirm performance will continue and we will have to keep on collecting data." (Respondent 7)

Where **post-closure monitoring** is concerned, hardly any regulatory requirements in the field or radiation protection exist today, and the overall position remains that 'geological disposal facilities do not rely on long-term post-closure institutional control as a passive safety function' (IAEA 2006). Several respondents nevertheless indicated to expect such recommendations to arise in the not too distant future.

"Where post-closure monitoring is concerned, we expect future recommendations that will tell us what is considered necessary, indispensable, or contrary undesirable." (Respondent 1)

"Anything we plan in terms of post-closure monitoring will depend on the conditions set by the regulator and by society – by our politicians and local stakeholders. … The position of our regulator today is that we should go as far as possible. So they are bound to come up with something, although the what and how of it remains unclear today." (Respondent 2)

However, the Swiss Nuclear Energy act clearly leaves all options open:

"After the repository has been closed in accordance with the applicable regulations, the Federal Council may stipulate that it must be monitored for a further limited period of time." (KEG: Article 39§3).

Furthermore, in some cases, other regulation exists that requires some form of post-closure monitoring. This is for example the case in Germany, where the Federal mining authorities require post-closure monitoring of any kind of mine, including a geological repository for radioactive waste:

"… monitoring of the mining structure is very common and required by the authorities" … ""According to our Federal Mining Act we have to monitor the mine. I don't know exactly how long , but at least for several decades [after closure of the mine]." (Respondent 12)

In its 2006 safety requirements for geological disposal, the IAEA too does not rule out the possibility and even potential value of post-closure institutional controls. However, more emphasis is put on the lengthy period before closure and the role of monitoring in passing on information to future generations to enable them to take decisions. Under the header 'requirements concerning post-closure and institutional controls' it is stated that:

> *"Geological disposal facilities are not likely to be closed for several tens of years after operations have commenced. Thus, plans drawn up to identify possible controls and the period over which they would be applied remain flexible and conceptual in nature. ... Arrangements will be made to pass on information about the geological disposal facility to future generations to enable them to make any future decisions on the geological disposal facility and its safety." (IAEA 2006: 32-33).*

2.2.2.3 Monitoring to reassure the public and build public confidence in a repository

There appears to be a general consensus within the expert community that monitoring has a major role to play in reassuring the public and in building public confidence in the repository. Both the IAEA and the ETN listed public confidence building as one of the key purposes of monitoring:

> *"... to strengthen confidence, for as long as society requires, that the repository is having no undesirable impacts on human health and the environment." (IAEA 2001: 3)*

> *"... to ensure that future generations will maintain confidence in the adequacy of the disposal system by confirming that the repository does not, at any time, pose a threat to the operating personal and the public, and the disposal system and the surrounding natural environment evolve as expected." (EC 2004: 11)*

Similar arguments were given by many of our respondents:

> *"The purpose of monitoring is to reassure the public and to show that what we do can be monitored and will be monitored and that we have confidence in what we are doing" (Respondent 5)*

> *"Monitoring has an important role: it allows the non-technical stakeholders to build up trust in the repository." (Respondent 13)*

> *"So they [the public, lay stakeholders, ...] rely very much on visualisation or a demonstration that it's safe, and the need would be that through monitoring one could sort of demonstrate with a few monitored variables that the repository is behaving in a safe manner. So I think it is the monitoring that is a bridge for the non-technicians to transfer technical details." (Respondent 13)*

This anticipation was furthermore confirmed by an external participant at a MoDeRn Workshop for Experts Stakeholders (mainly aimed at regulators), held in Oxford in April of 2011:

> *"Another external participant emphasised the importance of monitoring to lay stakeholders, noting that potential volunteer communities in his country had been asking detailed questions about repository monitoring well before potential sites for a repository had been identified." (Harvey and White 2011:19)*

2.2.3 Monitoring: to Provide Proof or to Make Transparent?

In 2007 a team of international experts invited by the IAEA to reflect on factors affecting public acceptance of geological disposal, listed monitoring as a specific technical requirement that could increase general acceptance.

> *"Acceptance appears to be increased when specific technical requirements, such as defence-in-depth, retrievability, **and monitoring**, are explicitly incorporated in the regulatory framework." (IAEA 2007: 40).*

The reason for this is that it is assumed that 'uncertainty about repository performance drives public concerns', and therefore that 'considerations highlighting robustness can mitigate those concerns thus increasing public acceptance' (IAEA 2007: 41). Following this line of reasoning, monitoring can help to demonstrate to the outside world that the experts know what they are doing and that geological disposal is indeed a safe option to manage the waste for several millennia. The question is whether that in itself would be sufficient.

During a MoDeRn workshop discussion in Madrid (October 2009) the argument was raised that in countries where repository plans become more concrete, local public stakeholders do seem to become more interested in monitoring, but that this does not necessarily imply greater acceptability:

> *"... monitoring is an issue they get more and more interested in.... but I'm not sure it has yet contributed to enhanced acceptability. Rather what I have detected is first use by stakeholders of the issue of monitoring to find the next Achilles heel in the repository process." (Participant B at Madrid workshop discussion)*

The same technical specialist was nevertheless convinced that the greatest advantage of monitoring in view of public confidence building, is the promise of transparency it brings:

> *"monitoring is a very powerful tool I think towards transparency ... I can see the direct link, for you can say: 'I want to have real data for example to show me whether there is radionuclide contamination of the environment or not. Okay, the process to me is transparent because I get continued verification that that's the case.' ... So, there's a direct link between transparency and monitoring, contributing to listing a few objectives I might be interested in and then looking at the results of monitoring." (Participant B at Madrid workshop discussion)*

The distinction made here is interesting, as it moves the focus from the product of monitoring to the process of monitoring. It could indeed be argued that it is not so much (or not only) the figures you produce to corroborate your claims and models that can support confidence building; but it is the fact that you produce them in such a way that others will have access to them, are able to control how they came about and will be able to give them meaning. From this perspective, it becomes important to know what expectations other interested parties may have of a monitoring programme, so that measurements can be made that relate to issues of their concern.

2.2.4 Experts' Perceptions of Public and Stakeholder Views on Monitoring

Most respondents admitted though that they had not as yet explicitly discussed monitoring strategies with local stakeholders or other members of the (concerned) public.

> *"It is true that thus far we have not considered making an analysis of the messages from society and what exactly could be the socio-political driving forces behind the question for monitoring." (Respondent 5)*

> *"... of course the siting has to mature a bit more, such that one has then a more specific plan of a few number of sites and the surface locations where we can really define the project such that one can talk about the technical details of the repository and perhaps also of the monitoring. So I think that ... these questions of monitoring would come up already next year, but that would be quite general, because the whole project of the repository wouldn't be matured enough to go into the detailed questions at that point in time." (Respondent 13)*

> *"My personal feeling is that from public hearings and discussing with people in for example church groups, or youth groups, ... that in the past we did not listen enough to these kind of people, to their expectations. ... We have discussed especially this topic* [i.e. monitoring] *and they are always wondering why we do not have a plan for monitoring and how to inform them of what is going on." (Respondent 11)*

This we also saw reflected in the Monitoring Contexts Report, where the evidence provided in the national context appendices suggested that relatively few countries have engaged with lay stakeholders specifically on the subject of monitoring (MoDeRn 2011). Many experts therefore found it difficult to anticipate what lay stakeholder expectations as regards to monitoring might be and whether they will be feasible to address.

Still some deduced from other interactions (e.g. the construction and operation of the URL in Bure) that the main concern of local stakeholders lies with the potential impact of the repository on the environment. The assumption is therefore that local and public stakeholders will mainly be interested in **environmental monitoring**, and not so much in near field monitoring.

> *"For developing our monitoring programme, we did not go through a stakeholder consultation. We sense though that this is something that preoccupies them and that they see monitoring as important. However we did not investigate explicitly what their priorities were. Something we do know, is that local people are concerned about landslips. That is an issue that has been raised on many occasions. But never specific expectations regarding the follow up of the repository, or the waste in itself. Local people's concern goes first and foremost to effects on the surface, impact on topography, etc." (Respondent 3)*

> *"In contacts with local stakeholders the emphasis is always strongly on the environment and surroundings, far less on the repository itself. For the moment, we do not have the impression that they foster explicit expectations regarding the follow up of the installation or the waste." (Respondent 3)*

From high-level technical documents, one could conclude that it is generally assumed that local stakeholders and the public will be particularly concerned with **post-closure monitoring**:

"In practice, institutional controls, including restrictions on land use, may be maintained even after the geological disposal has been closed. Such controls and monitoring are not necessary to ensure the safety of the facility; however, they may be regarded as additional measures for assurance." (IAEA 2006: 18)

"… continuing monitoring is likely to be a societal demand for some time after repository closure. Such monitoring, besides showing that the process of decommissioning surface facilities has been successfully completed, would also strengthen the confidence, at least in some sectors of society, that the evolution of the waste isolation system is in accordance with expectations." (IAEA 2001: 1)

This view we also heard echoed in several interviews:

"When retrievability is excluded, the main purpose of post-closure monitoring could be to give people reassurance and to build confidence." (Respondent 1)

However, when considering their own national contexts, many experts we spoke to place monitoring concerns from local stakeholders and the public in relation to reversibility and/or retrievability, and the possibility to intervene in case the repository system does not perform as expected. Arguably, this is more related to operational management **before final closure of the repository**:

"Last year we received some very specific questions [from local stakeholders]. All those that had to do with monitoring were directly related to the notion of reversibility. … Actually, those weren't exactly questions; more recommendations that we should continuously keep on monitoring. … What they [i.e. local stakeholders] *expect from us, is that we will permanently be 'on watch' and keep taking measurements" (Respondent 3)*

"You begin to get the feeling that people want to stretch the active phase as long as possible. As such, that is not too much of a problem, as long as you know the installation is there and you have the means and possibility to make sure no activity bearing negative impacts will occur. But you nevertheless need to prepare for the passive phase … Here monitoring could help, to demonstrate to people that we can move towards a passive system" (Respondent 8)

Based on the impressions of lay-stakeholder concerns that our interviewees expressed, it seems that there is a widely held perception that public and stakeholder expectations as regards to monitoring are strongly related to environmental impact, both in terms of the operational management of the facility and of long-term post-closure safety.

Whether or not local stakeholders or other members of the public in that respect hold strong opinions on actual monitoring strategies during construction and operation, or hold particular expectations as regards to post-closure monitoring, the accumulated experience of agencies in many countries tells us that people will be expecting openness and transparency about what is going on in the repository and how this may or may not affect the surrounding environment. In this respect, some respondents remarked that monitoring is not just about collecting data (and what measurements to make), but also about interpreting them and validating this interpretation, both within the expert community and within society at large:

> *"Monitoring is not only about putting in place the appropriate instrumentation, but also about what happens next: about the analyses and interpretation of results, about the (potentially endless) polemics that will follow on the reliability of the data." (Respondent 5)*

> *"I'm convinced that one day we will be able to put in place reliable monitoring instruments, but the analyses and interpretation of results will to a large degree always remain socio-political." (Respondent 6)*

So in order for monitoring to serve as an effective means of reassuring the public and contributing to building public confidence in the repository, both the product and process of monitoring will have to meet not only technical expert and regulatory objectives and requirements, but also public stakeholders' potentially diverse expectations.

Stakeholder expectations are the focus of Section 3 of this report but before turning our attention to that issue, we conclude this section by considering the key challenges experts see themselves faced with when developing monitoring strategies for geological disposal.

2.3 Key Challenges for Developing Monitoring Strategies For Geological Disposal

Monitoring for operational safety and regular environmental monitoring (in view of classical environmental impact assessment) are considered to be covered by existing regulations for nuclear facilities. In terms of technical implementation, experts do not see immediate challenges, as existing technologies applied today in other nuclear installations, such as interim storage facilities, are considered more than adequate:

> *"… monitoring would also be carried out for purely operational reasons during the emplacement of the wastes." … "Techniques and requirements for monitoring in these contexts are well established and tested in a wider sense (e.g. as for nuclear installations and mines)…" (IAEA 2001:3)*

> *"We decided that for the purpose of this project, we would not bring added value by further studying nuclear safeguards or operational safety." (Participant A at Amsterdam workshop discussion)*

What experts do see as a major challenge is the issue of **monitoring with the aim to provide assurance of post-closure safety**, or as phrased by the ETN 'monitoring to support evaluations and assessments of repository performance' (EC 2004). Such monitoring would be about **verifying if the assumptions on which the repository system is based are correct.** It is essentially situated in the pre-closure phase, but with an eye on future behaviour in a post-closure situation. The need for this kind of monitoring has risen more sharply with the (above mentioned) recognition that the evolution from an operational to a closed facility will be long (most likely stretching over more than one generation) and stepwise or progressive (some elements of the facility will be closed sooner than others); and that most likely a series of intermediary milestone decisions, as well as at least one explicit (socio-political) decision will be needed before final closure of a facility.

> *"During phased development of geological disposal, a series of progressively more detailed assessments of the long-term (post-closure) performance of the disposal system and its component subsystems will be carried out. These assessments will identify the key features and processes that determine performance and safety and, hence, will guide data collection, including guidance as to the collection of monitoring data to support future assessment phases.*
> *The purpose of the monitoring discussed in this section is:*
> - *To provide information in support of such assessments, in each phase of the system development;*
> - *To support decisions on when (or how; or indeed, whether) to move on to the next phase." (EC 2004:26)*

It is in fact the long-term safety component, focussing on what is to be expected after closure, which makes monitoring of geological disposal facilities such a specific challenge. For it is not just about what you measure - or do not measure - today, but also about what this implies - or could imply - for the models you use to predict future behaviour. As was described above (see Section 2.2.2.1), with currently envisaged techniques the features and processes that contribute to the long-term safety of a geological repository can only be monitored directly during the relatively short period of operational life of a repository and for a limited period post-closure.[9] All one can do is monitor to verify the predictive models that form the basis of the long-term safety case and, where appropriate, refine them in light of new data.

The necessary monitoring activity would therefore, be more challenging than is the case, for example, when monitoring for operational safety or environmental impact assessment because the avoidance of intrusion dictates that it will need to make use of indirect data. It therefore presents both technical *and* social challenges as it is, on the one hand, about defining measureable parameters based on available technology (as well as on anticipated developments in technology) and, on the other hand, about meeting - or renegotiating - different stakeholders' (e.g. implementers, safety authorities, neighbours, political decision makers, environmental NGOs, etc.) appreciations of what constitutes convincing confirmation of repository performance and long-term safety. Furthermore, given the long timescales involved, even if only considering the pre-closure period, a reasonable amount of flexibility is considered necessary for the monitoring programme to remain useful and effective for as long as it is required.

[9] Indirect monitoring, of groundwater for example, is of course an available option for as long as it is desired. But rather than monitoring repository processes this activity, depending upon on how one views it, either seeks to confirm through the absence of evidence to the contrary that these processes continue to conform to expectations or seeks evidence in the form of environmental change that they do not.

2.3.1 Monitoring for Long-Term Safety as a Techno-Scientific Challenge

Developing monitoring strategies for assurance of long-term or post-closure safety is considered by many of our respondents as still more of a question of R&D, than one of engineering and implementation:

> *"Anything that has to do with monitoring in the medium or long-term, receptors, etc., is very much focussed on the development and use of technology" (Respondent 6)*

> *"What we are looking at here is a matter that is outside regular activity. This is about a follow up over several decades … with an instrumentation that today has not been developed yet. This is more science than pre-engineering or pre-industry. … With monitoring we are still in a phase of development, of thinking about how this could be done. So we are still very much at the beginning, at the level of research and technical and scientific phrasing of the question." (Respondent 5)*

> *"I'm not prepared at this moment to say what exactly one should measure in what facility, how many instruments one should have and what one should do with the measurements, exactly how they should be used. I think it is not very appropriate for me to comment on those things at this stage. We have to develop them." (Respondent 14)*

Two elements are crucial here. The first is that of reconciling a need to collect data about repository behaviour with the need to avoid intrusive monitoring techniques that potentially could breach seals and compromise the conditions for passive safety. The second is the question whether or not there actually is something to measure, directly or indirectly, in the relatively short period before closure that would be conclusive enough to predict system behaviour with sufficient confidence to be able to exclude a future impairment of repository safety. Furthermore, the above statements make clear that a programme of performance confirmation includes not only monitoring activity, but also a long-term R&D programme that continues to develop monitoring technologies, testing and proving them in labs and URLs.

2.3.1.1 Reconciling active monitoring and passive safety

> *"The vast majority of organisations [refers here to waste management agencies] are basically saying very very little about monitoring and what they're going to do. And they don't say what they're going to do with the information. They make statements that are very broad about, you know, "Monitoring should be done, but it can't violate the integrity of the barriers" and then they leave it at that. But they don't say how you would do something that is inherently potentially contradictory." (Respondent 14)*

The above quote sums up nicely one of the biggest challenges monitoring experts are faced with today: The fact that some form of (in situ) monitoring will inevitably be needed is clearly recognised by most, if not all, implementers and by international reference bodies such as the NEA and IAEA. But how to do this without breaching safety barriers and thus risking a reduction in the overall level of post-closure safety is a question that as yet has not been fully answered.

"Limitations, on the other hand, arise from available monitoring technology; the need to respect all technical requirements of a repository monitoring context and in particular the constraints derived from the environmental conditions and the fact that monitoring activities must not interfere with the safety features and barrier performances of the repository." (MoDeRn – DOW: 7)

This is why in the MoDeRn project, an important part of the work is dedicated to investigating options for non-intrusive monitoring techniques.

"We have to bring in monitoring without weakening the safety functions. Certainly near the waste, this will have to be non-intrusive. You can only have intrusive monitoring, for example by putting a glass fibre through a seal, if you can pull it out later, before closing the repository. But the retrieval of wires may affect safety. So there are risks involved and you cannot compromise on safety. On the other hand for ***wireless monitoring*** *you need to emplace sensors, and the lifetime of most sensors is only 5 to 10 years. So the problems to be solved here are battery lifetime and the possibility of replacement. Through tubes, or something, but then you have to go in again. And then there is the problem of transmission." (Respondent 15)*

"During the next two years I have to come up with a monitoring concept for a high-level waste repository. So they [i.e. the regulator] gave me a large list of questions, for example, which should be answered or I should check whether they can be answered or not.

… a lot of questions concerning ***near-field monitoring****: What about radiation next to the canisters? What about chemical evolution of the minerals next to the canisters due to the heat, due to water and so on? … How can we monitor engineering barriers for example? How can we monitor, I am just repeating some of the questions, how can we monitor fluid migrations in the repository, mainly after closure of the repository, so in back filled areas? And one person said we will not be allowed to introduce any cable-bound devices in barriers or back filled areas, so we have to come up with new ideas of how to do this with wireless systems. And this is very specific and then there are a lot of questions concerning the environmental monitoring. What can be done at the surface? Do we have to use geotechnical equipment? Can't we make use of radar systems or satellite-based systems or mainly geophysical systems? Are we able to identify fluid movements from the surface in the underground facilities by using geo-electrical techniques or geometrical techniques or something like that? Such kind of questions." (Respondent 11)*

During a workshop dedicated especially to monitoring technologies, the MoDeRn consortium partners gathered information on wireless sensor networks and wireless through-the-earth data transmission, on fibre-optic technologies and geophysical techniques, on monitoring of groundwater and chemistry, on geotechnical monitoring, as well as on air-based and satellite-based monitoring. The conclusion was that some of these techniques indeed look promising and are likely to be of relevance for repository monitoring. However, techniques such as wireless data transmission, fibre-optics and geophysics, still require quite some further research to adapt them to the specific repository monitoring requirements (White *et al* 2010).

Hence also the firm objection all experts interviewed had to near field monitoring in the post-closure phase:

"Monitoring is something you associate spontaneously with some form of inspection after closure. But in the case of geological disposal, this is actually contradictory, as the concept explicitly does not rely on

active forms of control and intrusion for the purpose of inspection would be counterproductive." (Respondent 9)

"What will happen after closure, that will be extremely difficult to measure. The concept is after all designed to become passive in the end. The whole safety concept is based on that. Once all operational activity is behind us, and the risk of accidents has gone, then the host rock will take over and provide protection in case the waste containers fail." (Respondent 3)

But apart from finding technological solutions for monitoring without interfering with the safety barriers (i.e. answers to the question **HOW** to monitor), there is also continuing discussion about what exactly should be measured, which parameters are important, and what is feasible (i.e. answers to the question **WHAT** to monitor):

"Another problem to solve is the question of parameters: Which parameters do we need to take into account? What exactly are we going to measure?" (Respondent 15)

Rather than seeking definitive answers to these questions for once and for all, they are approached in an iterative manner in order to remain open to emerging and future possibilities.

2.3.1.2 Short-term monitoring for long-term safety

Questions of the feasibility and adequacy of monitoring particular parameters in order to support the safety case are particularly challenging in view of the extremely long time frames that are involved:

"The biggest uncertainties for us lie extremely far away from us: 10,000 to 100,000s of years; and these things we will never be able to measure." (Respondent 8)

Still most experts seem convinced that there are enough things that can be measured to give them a sufficient enough basis to validate (or if need be adjust) the models on which they build their safety cases:

"This is about phenomena that manifest themselves only very slowly, so one may assume measurements will hardly show anything in the first decades during operations. Monitoring over this period can nevertheless be of use, for if measurements go in the right direction, then we can be sure of our models, and not only our models, but also of long-term safety." (Respondent 3)

Furthermore, several respondents indicated that several decades of monitoring should be enough to make accurate observations and extrapolations for the long-term, as the most crucial phase, in which the waste is at its thermal peak, will manifest itself relatively early in the process:

"If no accidents occur in that period [i.e. an extended period of monitoring before closure of the facility], *it should be enough to make a comfortable estimate of safety in the long-term." (Respondent 3)*

"The thermal peak will manifest itself after 10 to 15 years, so after a few more decades we will be at the other end of that peak." (Respondent 4).

> *"What is of relevance is the transient phase: during the heat producing phase in the case of high level and spent fuel the repository is in a kind of transient phase. You have the heat, … but also thermal contraction. And the thermal contraction is a relatively dangerous situation, as it might produce cracks. Another point is the sealing, the shaft seals for example, okay it depends on the concept, but the time until the Bentonite or whatever is used, has saturated, consolidated and so on this lasts some several years. And after that time the situation becomes more favourable. And if you monitor this phase and nothing happened you can be relatively sure that nothing will happen in the future because the heat is out and everything has consolidated. So what more could happen after that?" (Respondent 12)*

But then it still comes down to deciding which parameters one would like to measure (largely depending on context: the environment in which the repository is situated; the character of the wastes involved, etc.) and which are actually measurable.

> *"I think we should focus on what is feasible and most likely. You cannot build scenarios on how to respond to something that is unlikely to happen for 10,000 years in advance. Moreover: who will be responsible for financing this?" (Respondent 2)*

This last remark brings to the surface that the question of what (as well as how) to monitor is in fact not only a question of science and technology, but also of economics and responsibilities. The challenges related to monitoring for assurance of post-closure safety may in large part be technical, but they also have an inescapable social component. We would therefore prefer to call them socio-technical challenges.

2.3.2 Monitoring For Long-Term Safety as a Socio-Technical Challenge

The inherently technical *and social* nature of the challenges facing monitoring for long-term safety, becomes particularly explicit when considering the element of time scales, and the question of reconciling different expectations within society with physical and technical constraints.

2.3.2.1 Monitoring, timescales and technological flexibility

The very reason why the waste management community is so passionate about geological disposal as the best available option for the long-term management of HLW or spent fuel, is related to the extremely long timescales involved in the management of higher activity radioactive wastes. Several reasons are given for this. First of all, there is the frequently made ethical argument that to store the wastes on the surface over such an extremely long timescale would place an unacceptable burden on future generations, which would be required to renew periodically the waste containment and to maintain it continuously in a safe state. The second argument is essentially a sociological one, which maintains that geological disposal represents a geo-technical solution to an inherently social problem: the impossibility of guaranteeing the active safekeeping of the waste if it remains on the surface *within* a society, the institutional and social stability of which cannot be assumed over time periods that exceed 300 years.[10] Hence the concept of passive safety, relying totally on engineered and geological barriers to safeguard life on the surface from the potential harm of radioactive contamination. Finally, for many northern and alpine countries it is the prospect of future glacial periods which may erode the surface to considerable depths that also makes the case for deep geological disposal so compelling. Geological disposal is therefore presented as a solution both to the failings and transience of societal institutions and to inexorable natural processes.

The extremely long timescale involved makes predictions on the future evolution of a facility, and therefore the potential future exposure of living beings to the radionuclides contained in the waste, uncertain. It furthermore makes it almost impossible to determine at the design stage all aspects of the monitoring programme to be carried out for the full length of the operations of the facility. Flexibility is therefore needed:

> *"As long as there are parts of the repository that are not passive, monitoring will remain a necessity, but it will not be done in the same way in every place of the installation, nor over the whole period of time. … You have to look at monitoring as an evolving matter and not something that we define once and for all in 2010." (Respondent 6)*

In many ways this is seen as a good thing, as a positive challenge:

> *"I see monitoring in a context of continuous R&D, of performance confirmation and continuously doubting ourselves and looking for possible ways of making our system better than it is today. We owe this to ourselves." (Respondent 8)*

> *"… this doesn't mean that throughout the project we will always monitor in the same way. Possibly we will follow-up on many things in the beginning of the project and evaluate and adapt this as we go along. It is therefore very likely that the ways of monitoring will change and that its intensity will diminish over time." (Respondent 3)*

> *"The logic is that monitoring serves to verify if it works. If we change our ways of working, or if we make changes to the concept in the course of the project, we will have to follow-up again until we are sure." (Respondent 3)*

Accepting the need for flexibility inevitably introduces new challenges and poses the further question of 'how flexible, and for how long?':

> *"The difficulty is that we do not know today for how long we will have to measure and observe. That does not make it easy to design sensors, for depending on which domain, those last on average today between 1 to 2 years, and 60 years. … That is our biggest problem. As long as we do not know for how long we have to measure, we can never tell if we have the right sensors or not." (Respondent 3)*

Maintaining flexibility in the monitoring programme in light of this continuing development may therefore present a variety of challenges, in particular that of

[10] 300 years is the figure commonly used within the sector when making statements about the period over which institutional control of the waste facility might reasonably be assumed.

accommodating regulatory, that is to say social, expectations which may themselves continue to develop.

2.3.2.2 Reconciling expectations with constraints

A last important challenge is that of developing a technically and financially feasible monitoring strategy that can meet technical expert and regulatory requirements, as well as a diversity of public stakeholders' expectations.

> *"I think that strategically we're in a very peculiar situation. We have a rather ill-defined situation where what comes in from society and from some of the reviews of disposal is that everything should be monitored. And then even the regulators themselves are saying: "We want monitoring". But they are also being very clear in saying: "Don't you dare monitor things in a way that will damage the barriers". Right? That's what they're saying. So the sort of clash of perspectives is pretty obvious." (Respondent 14)*

As mentioned above, the experts that we interviewed, in line with international institutions, assume monitoring to play an important role in building public confidence. For that to be so, both the product and process of monitoring would have to meet different stakeholders' expectations, while staying within the limits of what is scientifically sound and both technically and financially feasible. When developing monitoring programmes, this suggests that a dialogue with different types of stakeholders is needed, in order to develop mutual understanding of expectations and to address these in the design of the programme. Some see this as a source of conflict:

> *"So, you know, the public and society demand this, that you do something, and then there are the technical realities, and the regulatory requirements are also there, and all of them representing some sort of inherent conflict." (Respondent 14)*

Others are more optimistic, pointing to the need to give the public the opportunity to raise questions, and to invite them to make their concerns known:

> *"What we first need to do, is to gain confidence … and to understand their concerns. But I think we can answer a lot of their questions. The problem is that there are so many and that we cannot cover all of them in one go. It is a process that will develop in phases." (Respondent 8)*

> *"… this way you get into a situation or approach within which you try to process and reconcile everything you gather as input from different actors. It is about looking for a consensus. … We have now a period of some 10 to 15 years ahead in which we can cut the Gordian knot and decide together which way to go. Today we are at a stage where we can say we are sure that we can dig 600 meters deep, so that we are ok where safety is concerned. What rests are negotiations with just about everybody: with scientists, technical experts, the safety authorities, the wider audience, … . On plenty of issues this will not give rise to long and intense discussions, more a question of wrapping up certain issues." (Respondent 5)*

But even the more optimistic ones, were not entirely sure if there would be much use in focussing the discussion explicitly on monitoring. Most respondents saw monitoring as part of the bigger narrative of geological disposal, in which the question of monitoring inevitably will be treated, even if only indirectly, or subsequent to other issues:

"You need to discuss the whole issue. Just talking about monitoring is pointless. The first challenge for me is the whole issue about retrievability. As long as we aren't clear on that one, it makes no sense to go and discuss the parameters that we would like to measure. And in this respect it is important to talk about the fundamentals of the concept and about safety being the absolute priority. It is good that people can make their own judgement about that. This worked quite well in our dialogues[11]... It is important that citizens get to see that there are contradictory aspects and that we need to weigh these against each other. So we have to start discussing the concept and then start looking at what our stakeholders think important, why they think that important and what they think knowledge about certain parameters would contribute." (Respondent 8)

"In itself, monitoring may not give rise to much public interest, but once people start asking questions like: 'And how do you guarantee this will work?', … I think it will be in this way, that a dialogue on monitoring will take form. And it may very well be that at that point, some very technical questions will be put to us. Maybe we don't have much interaction on that subject today, but this will inevitably change at some point. Still, this is not likely to mobilize a crowd. We are talking here about a limited number of engaged and interested parties." (Respondent 5)

"Looking at monitoring in terms of performance confirmation, means demonstrating your repository is safe. You therefore cannot narrow this subject to discussing sensors and receivers. You have to frame it in a broader context and give people the chance to ask "Why would this site be safe? How can that be guaranteed?" (Respondent 2)

These observations raise important questions about the framing not only of the exploratory engagement process proposed as part of the MoDeRn project, but also how we conceive more generally the relationship between stakeholders and the development of repository monitoring programmes. That is the focus of Section 4 of this report but before turning to that we examine what we already know or can infer from existing research and published documents about stakeholder views and experiences of monitoring in this field and in other relevant contexts. This will be the subject of the following section.

[11] The Belgian respondent refers here to a number of stakeholder dialogues and a public forum held in preparation of ONDRAF/NIRAS' national waste management plan.

3 Stakeholders, Monitoring & Confidence

Published accounts of the relationship between stakeholders and monitoring activities typically focus on case studies of specific communities, projects or monitoring programmes. In this section of the report we summarise cases drawn both from the peer-reviewed research literature and from reports produced by organisations whose activities are focused on the field of radioactive waste management. Before beginning to examine those cases, however, a first point to note is that it was not possible to identify any studies published in peer-reviewed journals that investigated explicitly the views of lay stakeholders on geological repository monitoring, although there are studies that address other areas of monitoring activity. A number of reports recording the expectations and activities of stakeholders in relation to radioactive waste management have, on the other hand, been published in the so-called grey literature. The discussion that follows therefore draws upon studies on monitoring in other contexts together with other documentary sources reporting on practical experience to glean insights into this issue. There is, to begin with, research on stakeholder, particularly community stakeholder, views on and experience of monitoring associated with other nuclear facilities or with potential radioactive contamination. In addition there is research on citizen and stakeholder involvement in monitoring in a variety of other contexts, from air pollution to natural resource management. The issue of monitoring in relation to long-term radioactive waste management has been discussed explicitly by stakeholders in a number of the meetings and reports of the Nuclear Energy Agency, notably of its Forum on Stakeholder Confidence (FSC), as well as in various national contexts. These reports include contributions drawn from a variety of stakeholder constituencies and give valuable insight into current practices as well as an indication of stakeholder experience and expectations. A second point to note is that not only are the research studies and documents that inform this section of the report drawn from different operational or problem contexts, they also range across different national contexts. As will already be apparent from the preceding section, despite there being research problems and programme goals that broadly are shared across different countries, the political, economic, and historical context in each country has a very significant influence on radioactive waste management policies and practices. Any observations offered here are therefore indicative of potential stakeholder interests, preferences, and concerns rather than providing predictive or prescriptive conclusions. With that caveat, the primary aim of this review is to complement the investigation of expert (or technical specialist) views in the previous section by providing some insight into potential stakeholder interests and concerns in order to take these into account when developing the exploratory stakeholder engagement activities to be carried out within the MoDeRn project (WP1.4), the results of which will then help to inform the development of a repository monitoring reference framework, one of the final deliverables of the project (WP6).

3.1 Environmental, Socio-economic, and Participatory Monitoring

A distinction has already been drawn in the previous section of the report between different types of monitoring that may be carried out in the context of the construction, operation and long-term safety of a geological repository for higher activity radioactive wastes and spent (or 'used') fuel. Although the MoDeRn project is focused on strategies and technologies for monitoring repository and near field processes, when considering the role that monitoring may play in building and maintaining stakeholder confidence in a geological repository facility, it will be necessary to look to the overall monitoring programme associated with a repository project, as well as the network of relationships within which it is situated, when trying to answer the question of what is to be monitored, who that process should involve, and what roles the different actors might assume. Across the research literature reviewed, it is clear that most of the activities reported involve some sort of *environmental* monitoring. A further observation is that there is evidence of a variety of modes of organisation of monitoring, with one important feature being the extent to which a *participatory* approach is adopted. This aspect is singled out because it is consistent with the turn to collaborative or partnership-based approaches, involving the active engagement of stakeholders, adopted by radioactive waste management programmes in many countries, typically as a response to lack of stakeholder trust in implementing organisations or confidence in the safety of geological disposal. The remainder of Section 3 therefore summarises research findings on lay stakeholder attitudes towards monitoring and to experiences in different contexts, focusing in particular on radiological hazards. It includes examples of monitoring both the natural and the socio-economic environments, as well as examples of institutional, community and citizen monitoring activities. To begin with it considers environmental monitoring by local institutional stakeholders, including some examples that integrate monitoring of the socio-economic environment. It then looks at examples of monitoring for radiological contamination following known releases. It broadens this by bringing in examples of participatory environmental monitoring in response to concerns about other forms of environmental pollution before turning to examples of monitoring of radioactive waste and nuclear facilities, focusing in particular on the role of stakeholder and citizen involvement. Finally, it considers what the examples described tell us about the effects of these monitoring programmes on the stakeholders in these different contexts and activities, typically local citizens and community organisations, and on their relationships with experts, regulators and decision makers.

3.1.1 Environmental Monitoring

It was noted above that some of the technical specialists involved in the field of long-term radioactive waste management and geological disposal who were interviewed for the project had formed the view that citizens are primarily interested in environmental monitoring, seeing it as a source of reassurance that they and their communities are not being exposed to harmful releases of radionuclides. Our review of the literature suggests that this is indeed the most commonly cited type of monitoring demanded by or used to provide reassurance to citizens and stakeholders across a range of situations where radioactive materials or other hazards are concerned. Although the circumstances differ, the problem being addressed in almost all of these cases is one of public concern and information source credibility: the response is typically to establish monitoring arrangements that are perceived to be sufficiently independent and/or transparent for the results to be believed and for stakeholders to have confidence in the management of the situation. Importantly this does not necessarily mean that they automatically have confidence in all of the organisations involved in their particular situation but that, overall, they are assured that the source of their concern is subject to sustained scrutiny. In some cases this may simply entail the operation of a transparent system and monitoring and of reporting results by the operator of a particular facility; in others it may involve the development of complementary or autonomous monitoring mechanisms that can be used to discipline the operator for failure to meet socially acceptable standards by triggering regulatory sanctions. Between these two there are many variations and nuances. In what follows a variety of examples will be given to illustrate this. Some of them relate directly to monitoring of radioactive waste management facilities and some to other contexts but all of them highlight issues and experience that are relevant to the context of geological disposal.

3.1.2 Socio-economic Monitoring

Before moving on to outline these examples it is important to note that in addition to concerns about human health and environmental protection, local stakeholders may also be concerned about socio-economic and other impacts. In the first instance, this may involve concerns about the socio-economic impacts of a major construction project on the area and its communities. Monitoring socio-economic changes over time, using both quantitative indicators and qualitative data on community perceptions and concerns, can provide valuable information about trends and improve the management of the project (Glasson 2005). Glasson's study reports a study conducted during the construction of the Sizewell B nuclear power station in the United Kingdom, a site that already had an established nuclear power station but which had become the focus of national opposition during the public planning inquiry into its construction and where local residents harboured concerns about the impact of such a large project on their communities. Reviewing the results, Glasson (2005) argues that this type of monitoring not only enables timely intervention to mitigate negative impacts but that it can also be used to demonstrate positive impacts that deliver benefits to affected communities; a function that may contribute significantly to the formation of local attitudes towards a project.

An example of an integrated approach to environmental monitoring is provided by Clark County, Nevada, a metropolitan area which includes Las Vegas and four other cities. The County has a long history of sustained opposition to the proposed radioactive waste repository at Yucca Mountain. Wastes in transit to the repository would pass through the county, raising concerns about the effect of 'nuclear stigma' on the tourism economy[12] and about quality of life impacts, as well as public health and safety. Research suggests that, set in the context of the institutional politics of the siting proposal, opposition was strongly linked to distrust in the US Department of Energy (Pijawka and Mushkatel 1991). Clark County responded to the federal decision to focus on Yucca Mountain by developing a monitoring system to give it and its communities 'early warning' of any changes in the local environment (Conway *et al* 2009). When considering the range of indicators to be monitored the County decided to monitor not only the well-being of the natural environment and of public health, but also quality of life, socio-economic and fiscal well-being, resulting in a suite of more than 800 indicators. Indices derived from these indicators enable trends in the data to be tracked. After a period of development, the system went live in December 2004. It is accessible via a public website so that not only decision makers but also local citizens are able to review the results. The indicator monitoring is supplemented with annual focused interviews with local decision makers, a bi-annual survey of local citizens and a quarterly indicator report that summarises results and trends in a form that makes them easily understandable by the general public. Although plans for a repository at Yucca Mountain are currently in abeyance, Clark County is reported to have already derived benefit from its monitoring and information system. Although originally conceived as a decision support tool for the County, the system is also being utilised by four of the five local city administrations, as well as being adopted by public stakeholders for engaging citizens in dialogue about local service provision (Conway *et al* 2009). So here again we see that not only are environmental and health monitoring being integrated with a range of other variables but that the development of an integrated system may have benefits beyond that of reassurance by providing an information platform which creates new capacities and potentials for community empowerment and action.

[12] Research by Slovic *et al* (1991) was important in supporting this concern but the likelihood of sustained economic effects has been questioned by other researchers and a review of studies of several analogous situations concluded that although this effect was a possible consequence of repository siting in the State, the evidence available at that time could not confirm that it would occur (Easterling 1997).

3.1.3 Stakeholder Roles in Monitoring

These initial examples involve local government bodies establishing monitoring programmes and systems that reflect their areas of institutional interest and competence, albeit in partnership with other organisations. However, as we shall see, local monitoring initiatives can take a variety of forms and can involve stakeholders and citizens in different roles in relation to the monitoring programme. Several of the examples point to a more active role for citizens and their representatives in environmental monitoring. This reflects the convergence of a number of societal trends that can be observed around the globe:

- Firstly, the attempt by scientific and technical institutions to engage in a constructive way with citizens on science and technology issues, in particular where these relate to issues that are a matter of wider societal concern or which concern or affect citizens in particular geographical locations or social groups[13];
- Secondly, political recognition of and response to changing societal concerns about and changing expectations of the use of scientific and technical expertise in policy, leading not only to attempts to inform citizens but also to experiments in - and even requirements for - citizen engagement in the development and implementation of such policies[14]; and
- Thirdly, the appropriation by community-based organisations of the resources and tools of science in order to address environmental problems of local concern (e.g. the cases outlined by Ottinger and Cohen 2011).

Participatory monitoring is now widely used in natural resource research and management, both as a low-cost means of data acquisition where financial resources are limited and, importantly, as a way of engaging, educating and empowering local populations in the management of the natural environment on which their communities and livelihoods depend.[15] Some of these involve innovative uses of information technology to link communities and establish information networks (e.g. Mayfield *et al* 2001). Similarly, there are recent initiatives that involve citizens in monitoring natural

[13] This development was encouraged by academic researchers who critiqued institutional attitudes towards the 'lay' public, focusing in particular on the often implicit 'knowledge deficit' model which attributes public concern to a lack of understanding, and highlighting examples in which local knowledge and 'lay expertise' could be shown to offer valid insight into particular problems (e.g. Irwin and Wynne 1996).

[14] This has been driven, in part, by high profile failures of the system of policy expertise, such as that associated with the bovine spongiform encephalopathy (BSE or 'mad cow disease') outbreak in the United Kingdom (Jasanoff 1997), which had a profound impact on public confidence. The importance of a 'democratisation of expertise' for public confidence in policy expertise and in the institutions that use it is argued in EC (2001) and can be seen as complementing the institutionalisation of regulatory independence and transparency (e.g. Wales *et al* 2006).

[15] See, for example, the review by Conrad and Hilchey (2009) or the individual case studies provided by: Hartanto *et al* (2002); Kingham (2002); Robinson *et al* (2000); Savan *et al* (2003).

hazards and in helping to mitigate the risk to their communities. In a minimal example of participation, one such scheme simply utilises the capacities of individuals' home computers to create an earthquake sensor network, but at the same time helps to raise awareness and understanding of the hazard (Cochrane *et al* 2009). Another involves local people who live in earthquake-prone areas being trained to monitor movement on unstable slopes in order to gain early warning of impending landslide events (Karnawati *et al* 2009). Citizen and stakeholder participation in monitoring activities is therefore a trend that is appearing in many different fields beyond that of radioactive waste management.

3.2 Institutional Failure, Community Monitoring and Empowerment

Participatory monitoring of environmental hazards may not only be carried out but also initiated by citizens themselves, rather than by regulatory or other institutions. Typical circumstances would be where there is a perception of institutional failure and of consequent injustice. This may arise from a perception of institutional bias, for example if regulators are perceived to be too 'close' to the originators of the risks that they regulate, but may arise simply where resource constraints are perceived to affect the competence of regulatory agencies to monitor hazards effectively, so that agencies are perceived to be slow to investigate or to take action (see Freudenburg 1993). One well-studied example that illustrates this is the US 'bucket brigade' movement which monitors local industrial air pollution. Citizens groups receive training, from a small national NGO, in the use of simple, low-cost air quality sampling equipment (the eponymous 'bucket'); samples collected are then sent to certified laboratories for analysis. When the results confirm exceedance of permitted air quality standards, the community forwards the laboratory's report to the regulator for action (O'Rourke and Macey 2003; Overdevest and Mayer 2008; Ottinger 2010a). Care is taken to ensure the quality of data collected by community monitors; for example, to avoid *ad hoc* monitoring that may record unrepresentative data, bucket brigade activists in Louisiana have adopted monitoring procedures which replicate those used by the state environmental regulator (Ottinger 2010a).[16] Although these initiatives typically emerge as a consequence of a lack of confidence, by empowering citizens they may not only improve regulatory effectiveness by complementing agency capacity but may also have other important social consequences, a point to which we return in Section 3.5. Before that we turn to examples of monitoring at radioactive waste management and other nuclear facilities.

[16] Ottinger (2010b) develops this point, noting that the empowerment experienced by citizens in her study arises not merely from the collection of independent data but from the strategic interpretation and utilisation of those data, and identifies three specific ways in which this is expressed: as giving them power to define the issue; power to enforce regulation; and power to make choices.

3.3 Participatory Monitoring in Response to Known Radioactive Releases

A similar turn to stakeholder involvement and citizen participation in monitoring can be found in a number of contexts that involve the management of radiation hazards. There are, to begin with, several examples from the USA, extending back over more than 30 years, of citizens participating in environmental radiation monitoring in situations where there were known to have been releases and where as a consequence there were local concerns about contamination. Here we outline three cases that are well documented in the research literature: Three Mile Island, the Nevada Test site and Amchitka Island.

3.3.1 Three Mile Island, Pennsylvania, USA

The first of these programmes was established with the communities around the nuclear power plant at Three Mile Island (TMI), Pennsylvania following the accident there in 1979, during which there was a relatively small release of radioactive material. The accident eroded community trust not only in the facility operator but also in the Nuclear Regulatory Commission (NRC), leading many affected citizens to mistrust all officially sourced information. The local communities were therefore very hostile to proposals to release low levels of radioactive krypton-85 gas from the damaged reactor in order to proceed with clean up, even though the NRC had judged the venting to present no threat to human health, and to plans to reopen the undamaged second plant on the site (Walker 2006: 226). The situation was therefore one of mounting conflict. The Department of Energy responded by bringing together a team which included experts from the Environmental Protection Agency, the Pennsylvania Department of Environmental Resources, Pennsylvania State University and a technical consultant to design, in close collaboration with local state and municipal officials from within a five-mile radius of the plant, a programme that would address citizens' concerns and information needs and provide a basis for their assent to the venting of the gas going ahead: this resulted in the Three Mile Island Citizen Radiation Monitoring Program (TMI-CRMP) (Baratta *et al* 1981; Gray Gricar and Baratta 1983). The citizens who were to carry out data collection for the monitoring programme were chosen by the members of each community and given the necessary training by the agencies. Community members had greater confidence in the resulting data because they had far greater trust in the individuals who were collecting it but also, as an outcome of the process, in the government agencies involved in the programme. The venting of the krypton gas subsequently went ahead, closely monitored by the community network. The practical outcomes of this participatory monitoring programme offer an effective illustration of the benefits of adopting a collaborative approach that includes the whole range of stakeholders (Gray 1989). Interestingly, although the original monitoring programme was established to address what was seen to be a problem with a relatively defined time span and despite the improvement in public confidence and community relationships that resulted, in 1989 a successor network, the TMI Citizens' Monitoring Network (TMI-CMN), was set up with financial support from the TMI Public Health Fund by a small group of local citizens who continued to be concerned about their radiological environment.[17] This network, which has about 30 members, is therefore quite different to the Department of Energy (DOE)-sponsored collaboration that was established in 1979, although it involves citizens engaging in similar monitoring activities. It can be seen as evidence of continued distrust on the part of some local citizens of information provided by regulators or by the company that operates the nuclear power station, but also of reluctance to relinquish the sense of empowerment gained through active involvement in monitoring.

In another development arising from the TMI event, a not-for-profit organisation, the EFMR Group, was established by a local citizen which facilitates radiological monitoring by citizens and which also has the educational aim of increasing community understanding of radiation; in this capacity it has worked with a wide range of groups, including the Nuclear Regulatory Commission, the Environmental Protection Agency and the Los Alamos National Laboratory.[18] Radiological monitoring by citizen groups also goes on at US sites other than TMI, such as the C-10 Radiological Monitoring Network around the Seabrook nuclear power plant in southern New Hampshire, which has been in existence since 1990.[19] In all of these cases, if elevated readings are recorded by local volunteers the group contacts the site operator and the Nuclear Regulatory Commission for clarification of the likely cause.

3.3.2 The Nevada Test Site, USA

The TMI-CRMP became the model for another initiative in participatory monitoring of radionuclides in the environment, the Community Environmental Monitoring Program (CEMP), that was established in 1981 around the Nevada nuclear test area, where the USA conducted weapons testing until 1992 (Douglas 1983; DeSilva 2004). Rather than concern about the effects of an unintended event (and the corrective measures involved in dealing with it), as was the case at TMI, here the concerns among local populations were about the health effects of a series of planned events. Like the TMI CRMP, the CEMP was initiated as a collaboration between: the DOE; the Environmental Protection Agency (EPA); the Desert Research Institute (DRI), a local higher education institution; and the communities bordering the test site. Local citizens were trained to operate a network of monitoring stations that was established around the test area (school teachers have

[17] Brief information about the TMI-CMN can be found at: http://www.tmi-cmn.org/index.html
[18] Information about EFMR can be found at: http://www.efmr.org/index.html
[19] Brief information about C-10/RMN can be found at: http://www.greens.org/s-r/11/11-21.html

been particularly well represented in this role). At its inception in 1981 the network had 15 monitoring stations ranged around the test area and across three contiguous states: California, Nevada and Utah. In 1999 administration of the programme was transferred from the EPA to the DRI and by 2007 its network had been extended to 29 stations spread across 160,000 km^2, using state of the art equipment and trialling new environmental sensors (Hartwell and Shafer 2007). In addition to maintaining the monitoring stations, the trained community monitors respond to questions from local citizens and engage in outreach to their communities, thereby acting as a two-way channel of communication and ensuring that the regulatory agencies are aware of local environmental concerns (Hartwell *et al* 2001).[20]

3.3.3 Amchitka Island, Alaska, USA

One final example is Amchitka Island, Alaska, which was the site of three underground nuclear weapons tests in the late 1960s and early 1970s. Despite scientific assessments following the tests, there was little monitoring of local biota after the 1970s and there continued to be concern about possible contamination (Benning *et al* 2009). The US DOE's proposal to 'close' Amchitka and end its responsibility for the site heightened those concerns, which led to the establishment of the Consortium for Risk Evaluation with Stakeholder Participation, a collaboration between federal and state agencies, stakeholder groups, including indigenous Aleut people, and scientific researchers. Instead of a conventional stakeholder communication approach this initiative involved Aleut hunters in collecting data, thus utilising their knowledge of the island and of the fauna that are found there (Burger *et al* 2009). Outcomes included reduced Aleut concern about radionuclides and an increased interest in monitoring ecological changes (Burger and Gochfeld 2009). Furthermore the inclusive and collaborative approach not only addressed a significant data gap but empowering local citizens and stakeholder groups also resolved the conflict which hitherto had characterised the situation (Burger *et al* 2009).

[20] Another participatory initiative focused on the Nevada nuclear test area, the Nuclear Risk Management for Native Communities Project, was established as a collaborative research project by researchers from Clark University in Massachusetts and the Citizen Alert Native American Programme based in Ely, Nevada (Quigley *et al* 2000). Unlike the CEMP this had a fixed life of four years; nevertheless, it combined educational and action-oriented goals that aimed to equip the local Ely-Shoshone people, who felt that their needs were not being met by existing institutional arrangements, with additional resources that would enable them to continue their activities beyond the life of the project.

3.4 Monitoring Associated with Radioactive Waste Management

Turning to monitoring associated with radioactive waste management activities and with the operation of waste facilities or repositories, we can find a number of cases that are directly relevant to the MoDeRn project for what they can tell us about the concerns and expectations of stakeholders in particular contexts and about the arrangements that have been arrived at to address these concerns.

3.4.1 The Waste Isolation Pilot Plant, New Mexico, USA

One of the few examples of an operating geological repository is the Waste Isolation Pilot Plant (WIPP) in New Mexico, USA, which began disposal operations in 1999 and which accepts transuranic wastes generated at nuclear weapons facilities. Surveys tracking public attitudes over a period of 11 years, from before the opening of the facility into its operational phase, found mixed views across the State of New Mexico, with acceptance of the facility highest in the area closest to the repository (Jenkins-Smith *et al* 2011). Key stakeholders in the local community of Carlsbad are enthusiastic champions of the facility, currently lobbying for a high level waste facility to be sited there[21], and monitoring plays an important part in demonstrating the safety of the facility and in maintaining local confidence in its operations. Monitoring is carried out by the Carlsbad Environmental and Monitoring Research Centre (CEMRC), which was set up in 1991 in a local college of New Mexico State University to conduct independent health and environmental monitoring and to disseminate the results (Conca *et al* 2008). Funding came from the DOE, although CEMRC carries out its work independently of the DOE and its data are not used for regulatory compliance purposes. Its radiological monitoring covers not only all relevant environmental media but also whole body dosimetry of volunteers recruited from the community. The CEMRC's analyses provide an independent check on those carried out by regulatory and other organisations, providing assurance of their reliability to local decision makers and to other members of the local community. Even before Carlsbad set up the CEMRC, the State of New Mexico had established, in 1978, an Environmental Evaluation Group (EEG) to provide independent scientific expertise and oversight of the WIPP project. This independent scientific oversight extended to scrutiny of the geological and hydrogeological data and of the assumptions informing the performance assessment for the WIPP. From 1985 onwards the EEG also carried out radiological monitoring around the WIPP site and in neighbouring communities. The EEG was disbanded in 2004 and a contract for independent technical oversight and evaluation was awarded to a private company, PECOS Management Services Inc., which continues to be funded by the DOE (Bergmans 2010; NEA 2010a).

[21] As evidenced by an address given by former Mayor of Carlsbad, Robert Forrest, to the WM2012 conference, Phoenix, Arizona, 29 February 2012.

3.4.2 Nye County, Nevada, USA

The case of Clark County, Nevada, which has been opposed to the Yucca Mountain (YM) project, was outlined above. Another Nevadan county has adopted a rather different stance but some similar measures. The Yucca Mountain site is located within the Nevada Test Site (now known as the Nevada National Security Site), which in turn is situated in Nye County. The county therefore has long experience of nuclear issues and has adopted what it describes as a 'constructive' approach towards the YM project, seeing it as a potential source of economic benefit. Under the amended Nuclear Waste Policy Act, local government units such as Nye County that are affected by proposals for Yucca Mountain are accorded specified rights of participation, funding and on-site representation. Nye County set up a Nuclear Waste Repository Project Office (NWRPO) which engages in monitoring and testing studies, focused in particular on geology, hydrogeology and engineering (NEA 2008). One of the objectives of NWRPO's Independent Science Investigation Program (ISIP), established in 1994, is the reduction of uncertainty in DOE Yucca Mountain Project performance assessment models. Data are collected in accordance with a Quality Assurance programme that has been reviewed by the Nuclear Regulatory Commission[22] and are shared with the DOE, as well as being publicly available on the NWRPO website.[23] Financial support for this initiative came from the DOE, which provided funds to the State of Nevada, to 10 affected counties, and to the Timbisha Shoshone Tribe to enable them to conduct independent scientific oversight of the Yucca Mountain project (Bergmans 2010: 28).

The Carlsbad and Nye County cases are examples of local government institutions that are broadly supportive of repository projects engaging in monitoring activities to ensure and to contribute to the safety of the facility. Importantly they also demonstrate that stakeholder institutions choosing to carry out independent monitoring and evaluation is not only associated with opposition but may also be a necessary basis for confidence and credibility in the context of constructive engagement with a repository project. Finally, unlike many of the other examples given, where the focus was on environmental monitoring for possible contamination, these two cases also show local stakeholders reviewing critically the scientific basis for assessing future repository performance, with this extending in the case of Nye County to an independent programme of data collection.

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[22] U.S. Nuclear Regulatory Commission Acceptance Evaluation for Nye County Quality Assurance Program Plan, March 1999.

[23] http://www.nyecounty.com/LSN/index/EWDP/water_data.htm

3.4.3 Port Hope, Ontario, Canada

The municipality of Port Hope in Ontario, Canada has been dealing with a legacy of low level radioactive wastes arising from more than 40 years of radium and uranium processing. Although there had been earlier phases of clean up during the 1970s, there were remaining areas within the town still to be remediated. In the late 1980s an informal network was assembled involving national regulatory bodies and the local municipality that drew up a Remedial Action Plan (RAP) focusing on contamination in the town's harbour. The RAP allocated clear responsibilities to all of the partners, including a Community Liaison Group which assessed the potential impacts of the contaminated sediments and reviewed all of the mitigation and remediation options. The successful implementation of this collaboratively structured and managed process was seen as a success story by national regulators and as a model to be emulated elsewhere (Weston 1995). Building on this successful collaboration the community and the regulators explored and proposed solutions for the remaining LLW clean up and for the *long-term management* of the wastes. This resulted in 2001 in a legal agreement being signed and the Port Hope Area Initiative (PHAI) being established. Central to this agreement is the understanding that the Federal Government has responsibility for the wastes and importantly for the long-term management, monitoring and maintenance of the final LLW waste facility but also that the community has control of the final project solution (NEA 2003: 57-58). During the FSC workshop held in Ottawa in 2002, presentations and discussions about the Canadian situation, referring not only on the example of Port Hope but also to others drawn from the mining and waste management sectors, emphasised repeatedly the importance for community confidence of transparent environmental and socioeconomic monitoring including, in more than one case, the creation of a role for local interests in monitoring a facility (NEA 2003: 106-107).

This Canadian case also serves to highlight the importance of context and of the overall set of arrangements within which monitoring is taking place for the degree of public confidence in the process. As well as adopting a collaborative approach to the clean up project, with open reporting to the affected communities[24], an important feature of the PHAI is that the Municipality has its own Peer Review Team (MPRT), delivered by a multidisciplinary consultancy firm in collaboration with a network of other specialist consultants as required, which can provide independent scrutiny of technical documents and ensure their quality, thus enabling the municipality to propose as well as to accept or reject remediation and long-term waste management measures. The MRPT reviewed the 16 volumes of the initial Environmental Assessment Study Report that subsequently

[24] The Port Hope Area Initiative involves two projects, one addressing the long-term waste management problem in Port Hope itself and the other in neighbouring Port Granby.

provided the basis for the reports to date. The now long-established collaborative relationship has improved confidence in regulators (Gardiner *et al* 2011) but it is clear from the emphasis given to the role of the Municipal Peer Review Team on the community's website that having the technical capacity to evaluate critically the basis of remediation and long-term waste management proposals is important to that confidence.[25] The Municipality consequently has a very strong sense of local ownership of the solution, presenting it to local citizens as a 'made-in-Port Hope Project [...] using environmental criteria for the clean-up that are specific to circumstances in this community'.[26] Although this has not eliminated all concern about environmental and health risks in the local community (see, for example, Fried and Eyles 2011) the Municipality reports steadily increasing levels of citizen confidence, with 84% of the residents who responded to the 2011 attitude survey expressing confidence in the ability of the PHAI Management Office to safely manage the waste for the long term.[27]

3.4.4 Meuse/Haute-Marne Underground Research Laboratory, Bure, France

France provides another example of local communities becoming engaged in monitoring programmes but in a way that is institutionalised in formally recognised local bodies with prescribed roles and functions. The Local Information and Tracking (or oversight) Committee (*Comités locaux d'information et de suivi* or CLIS) established to represent local stakeholders in the process of siting, constructing and operating an underground rock laboratory (URL) at Bure is an institutional development, based in provisions introduced in the 1991 Waste Act. The Waste Act also introduced the requirement for wastes to be retrievable from a repository, thereby ensuring an important role for monitoring to provide the necessary information about the repository system (Kriguer, in NEA 2010b, p. 10). During discussions at the 2009 FSC workshop French stakeholder representatives clearly expressed the view that monitoring by the implementer and regulator was necessary but was not sufficient for stakeholder confidence, emphasising the need for independent laboratories also to be involved (NEA 2010b: 36). The importance of independent monitoring is borne out by the results of a questionnaire survey, which found that the CLIS's involvement in environmental and health monitoring is the role that, together with the provision of information, is most valued by its local citizens (Colon, in NEA 2010b: 15). Although environmental monitoring is required to meet regulatory requirements, the CLIS contracted an independent review of the environmental monitoring plan produced by the implementer, Andra, and insisted on additional measures to those proposed for water and radiological monitoring (NEA

[25] The relevant page, including links to the Municipal Peer Review Team's main reports, can be found at: http://www.porthope.ca/en/residentservices/peerReviewTeam.asp.
[26] http://www.porthope.ca/en/residentservices/what_is.asp
[27] http://www.porthope.ca/en/residentservices/Commentary.asp

2010b: 33). The CLIS has also pressed for epidemiological surveillance and although attempts to establish a regional programme were unsuccessful, it formed its own environment and health group in order to maintain a watching brief on this issue (*ibid*.).

The Local Information Commission (CLI) at Soulaine-Dhuys in France, which since 1992 has been host to the Aube repository for low and intermediate level radioactive waste, also took the step of commissioning independent radionuclide monitoring around the facility following the discovery of 'hotspots', even though these did not exceed regulatory limits. The Mayor of the community, also addressing the FSC workshop in France, spoke of this as the CLI 'waking from its torpor'; he also noted that by taking this initiative it increased its credibility (NEA 2010b: 33). He also maintained that independent expertise is 'fundamentally necessary' if local stakeholder bodies such as the CLI are to move beyond polarisation into pro- and anti-nuclear sources and achieve local confidence and support.

3.4.5 Vandellòs i l'Hospitalet de l'Infant nuclear power plant, Catalonia, Spain

We find a stakeholder body taking on a similar role to that of the CLIS as part of the decommissioning process at the Vandellòs i l'Hospitalet de l'Infant nuclear power plant in Catalonia, Spain. The Spanish National Radioactive Waste Management Company (ENRESA) conducts its own environmental monitoring programme at the site (Ortiz *et al* 2004), which is overseen by the regulator. A Decommissioning Information Committee, comprised of representatives of national, regional and municipal government bodies, was also established to oversee the decommissioning process. [28] In addition to these institutional arrangements, however, representatives of affected municipalities wanted closer scrutiny of the process. The outcome was the formation, with the cooperation of ENRESA, of a local Municipal Monitoring (or Tracking) Commission to provide local oversight of all aspects of decommissioning (ENRESA 2004). The role of this commission included oversight of radiological and other forms of environmental monitoring, and of other surveillance and control systems including those governing work process, on-site safety and materials management. Membership of the Commission included representatives of the affected local municipalities and of regional government, of local commerce and trades unions, of the power plant and of ENRESA (NEA 2007b). One additional member organisation, the Rovira i Virgili University (URV) of Tarragona,

[28] The national Association of Municipalities in Areas with Nuclear Power Plants (Asociación de Municipios en Áreas con Centrales Nucleares - AMAC), formed in Tarragona in 1988 and now extended to cover other nuclear facilities, has promoted the formation of local committees for monitoring and information provision at nuclear power plants. Nevertheless, despite its undoubted contribution to the development of the capacities of these communities, a sociological study of AMAC concluded that its level of empowerment is relatively low (Garcia Hom and Sáez Giol, undated).

played an important role in enhancing the capacity of the Commission to provide oversight of the decommissioning activities. URV's Environmental Analysis and Management Group provided technical advice, undertook independent review of ENRESA's reports and helped to 'translate' technical information to make it accessible to local citizens; this was seen as an important innovation by the local municipalities and supported the Commission's communication with the wider community (Castells, p. 15; Castellnou, p. 69; in NEA 2007b).

3.4.6 Radioactive waste storage and disposal facilities, Hungary

One final case, which displays many of the same features as the preceding examples but which introduces an important additional development, is that of the public oversight and information associations (POIAs) established at Hungarian radioactive waste management and disposal sites. Licensees of Hungarian radioactive waste facilities are required to support the formation of POIAs at their sites. POIAs have been established for each of the country's radioactive waste management sites, including the interim spent fuel store at the Paks nuclear power plant (NPP), the near surface low and intermediate level waste (LILW) repository at Püspökszilágy, the planned new LILW repository at Bátaapáti, and the potential high level waste repository location at Boda (NEA 2009: 5). These associations perform a role that in many respects is the same as that of the French CLIS de Bure, in particular; their role in monitoring, however, goes further than that of the CLIS. The first POIA was established in 1992 during the planning process for the interim store at the Paks NPP. Its role at that time was to monitor background radiation levels and to provide information to the local communities. It did this, with financial support from the NPP operator, by commissioning independent experts to collect data from monitoring equipment sited in the communities (Vári and Ferencz 2007). This role has developed, however, with POIAs playing an important role in mediating the relationship between implementer and communities. Their approach to their monitoring responsibilities has also evolved and they have now developed what amounts to a monitoring *partnership* with the implementer and the regulator. Rather than simply calling on independent experts to check the monitoring carried out by the implementer and overseen by the regulator, members of local communities are now involved in inspecting waste packages received at the facilities and also in taking various monitoring measurements in and around the facility, a role for which they receive individual training that takes around one year (NEA 2009).

The role undertaken by the Hungarian POIAs is in some ways similar to the citizen environmental monitoring carried out in the USA that was described earlier in that it involves citizens taking responsibility for participating in monitoring activities. It is also distinctive however in that none of these other examples involved citizens carrying out direct inspections *within* an operational facility rather than being restricted to conducting monitoring of the environment around it. In discussing the Canadian example of the Port Hope Area initiative above we noted the importance of the institutional context and relationships within which monitoring was taking place for confidence in the process. This is also highlighted in the Hungarian case where research has found that the activities of the POIAs are significantly influenced by their social and political context; for example, stakeholders at the planned HLW repository site at Boda have been reported as expressing concerns about the stability of the national radioactive waste strategy as successive political changes resulted in interruptions to the repository research programme, which raised concerns about its lack of transparency (Vári, in NEA 2009). Vári and Ferencz (2007) note therefore that while it is possible to find some evidence for transparency at a local level, this has not been the case in relation to the regional or national level; a condition that could therefore undermine local confidence.

3.4.7 Local Processes, External Events and Stakeholder Confidence

This last point, about the potential impact of events at the national level, raises an issue that is significant for this report: repository siting and development programmes tend to focus on building constructive relationships between implementer and communities *at the local level*. Many of the examples given in this section represent just such initiatives; others have been a response to perceived or real failures at institutional level. However, interactions between events and processes at *different levels* of political and institutional organisation have the capacity potentially to destabilise relationships that have painstakingly been developed among a network of actors at local level. This brings to mind Slovic's often repeated axiom about the 'asymmetry' of trust - that it is much easier to destroy than to create – and his observations about the way in which wider social institutional and technological changes may have pronounced consequences for public confidence in specific technologies and projects and for the functioning of trust relationships in these contexts (Slovic 1993). At the same time, the element of contingency and of susceptibility to apparently 'external' influences that this interconnectedness introduces also suggests that it is not possible to apply a simple metric of trust that could predict its stability in the face of disruptions to established relationships.[29] As Gooday (2004: 272) suggests, 'the business of trusting people,

[29] Poortinga and Pidgeon (2004) point to the influence of prior beliefs on the extent to which trust is resilient to such perturbations. Nevertheless, those beliefs may themselves be shaped by prior events in the wider national or even international context. This is clearly illustrated by Poortinga and Pidgeon's own example of genetically modified organisms (GMOs) in the UK. In that case a series of apparently unrelated issues, most notably that of expert misjudgement and government mishandling associated with the outbreak of bovine spongiform encephalopathy (BSE or 'mad cow disease') and its links to the human condition of Creutzfeldt-Jakob Disease (CJD), influenced public beliefs about the expert advisory system and about government management of food-

instruments, and materials is in many ways a subject beyond measurement'. Having noted the significance of contingent contextual factors, however, it is clear that the cases presented here, despite being drawn from a variety of national contexts, display a number of commonalities and recurrent themes. These are discussed in the remainder of this section, beginning with a review of the positive outcomes reported in many of these examples as a result of citizen stakeholder participation in monitoring activities.

3.5 Concluding Observations

3.5.1 Positive Outcomes Claimed for Stakeholder Participation in Monitoring

Several of the studies reviewed note that involvement in monitoring can contribute to learning by increasing stakeholder *awareness and understanding* of the nature of the problem and also of the science that underpins its management (e.g. Gray 1989; Hartwell *et al* 2001; Burger and Gochfeld 2009). It can also mediate the relationship between citizens and experts in new and potentially constructive ways (Ottinger 2009).

3.5.1.1 Increasing confidence in monitoring and management programmes

Importantly there is evidence from several of these cases that some form of participation can increase stakeholder confidence in monitoring and management programmes. The study of participatory environmental monitoring on Amchitka Island, Alaska, found that not only did the Aleut people become less concerned about radionuclides but that they also became more trusting of the experts involved in the programme (Burger and Gochfeld 2009). Similarly the Three Mile Island Community Citizen Radiation Monitoring Programme (TMI CRMP) helped to re-establish public confidence in information about the facility, which had declined significantly as a result of the 1979 accident, by involving them in the collection of data (Gray Gricar and Baratta 1983). The Nevada Test Site Community Environmental Monitoring Programme (CEMP) also reports greater public confidence in monitoring results as a consequence of involving citizens in data collection (Hartwell and Shafer 2007). All of these cases have in common a situation in which there was public concern about radionuclide contamination following either intended or unintended releases. Enhanced confidence has also been reported, however, in those countries where stakeholders have been involved in defining monitoring arrangements or in carrying out monitoring activities at radioactive waste and nuclear facilities. For example, in the case of the Belgian surface repository for low-level waste, local stakeholders were concerned about the risk presented by the high ground water level; engagement at the design stage led to

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related risk, which in turn affected confidence in expert evaluation and government handling of the risks associated with GMOs (Simmons and Weldon 2000).

modifications that created a space beneath the repository where this could be readily monitored, satisfying stakeholder concerns and increasing confidence in the safety of the facility (Bergmans *et al* 2006).

> *"Local monitoring of an RWM facility is an arrangement that promotes acceptance by increasing trust and perceived security. It is also appealing to those focusing on justice, since it empowers the less powerful."* (Vari, in NEA 2004c: 82-83)

3.5.1.2 Added value: enhancing social capital and community capacities

Another, wider, social consequence of the active involvement of citizens themselves in monitoring programmes lies in its potential for enhancing social capital; that is, the integrative social fabric of a community, by developing new social capacities, enhancing mutual understanding and social relationships, and fostering more active forms of citizenship.[30] It may do this by enhancing both 'bonding' social capital - the links that bind a group or community together, including their sense of having shared goals and identity - and 'bridging' social capital – which involves enhancing the quality of relationships across social boundaries and the benefit derived from those links (Putnam 2000), for example between citizens and 'external' institutions such as implementers and regulators.[31] This therefore goes well beyond the idea that it is essential to understand the social context of communication about risk and risk management and its effect on stakeholder concerns and priorities (Johnson 1987), an insight that has been acted upon by many organisations in the radioactive waste management sector over the past decade or more. Instead it looks to the ways that interventions and mechanisms introduced to address such concerns, and associated tensions or conflicts, may in turn have unintended but beneficial consequences, not only for the community but also potentially, through the production of a virtuous circle of positive outcomes and relationships, for the organisations and institutions involved. This is consistent with the 'added value' model of community benefit advocated by the FSC, which goes beyond thinking simply in terms of financial benefits to look for ways of enhancing community well-being, and points to ways in which some form of participatory monitoring might contribute to achieving that goal (NEA 2007a).

[30] Several examples from outside the radioactive waste field are cited in the review by Conrad and Hilchey (2011).

[31] Although even when citizen involvement in monitoring enhances the capacity of regulatory institutions, there may continue to be epistemic differences; that is, different understandings on the part of experts and non-experts about what constitutes evidence and proof (Ottinger 2009).

3.5.2 An Active Role for Stakeholders

The preceding paragraphs identify some positive consequences of involving stakeholders in monitoring programmes. Although there are significant differences between the environmental monitoring that is the focus of most of the examples given and monitoring a geological repository, these examples demonstrate the potential value of stakeholder participation. However, the examples that have been discussed, although reflecting experience of monitoring programmes across different contexts and taking different forms, also suggest a number of other observations about lay stakeholders and monitoring, some of them cautionary in nature.

The first observation is that, where there is perceived to be the potential for environmental contamination, however small the risk, in terms of technical expert assessments, that this might present to the natural environment and human health, environmental monitoring typically plays an important role in reassuring local citizens and stakeholder representatives of the safety of a facility. A second point of note is that where there is distrust of the competence or good faith of regulatory or other risk management organisations, and particularly where this is associated with a sense of injustice, citizens and stakeholder groups are likely to seek ways in which they can commission or conduct their own monitoring.[32] A third, related point is that the evidence suggests that the *active* involvement of citizens in environmental monitoring can contribute to building and supporting public confidence – or at least to addressing mutually reinforcing experiences of distrust, vulnerability and powerlessness that can lead some citizens, or even whole communities, to adopt a stance of resentful or hostile resistance (Simmons and Walker 1999). The emphasis given here to stakeholders taking an *active* role should not be taken to suggest that individual citizens necessarily should – or would want to – be involved in collecting data, as in the case of the US bucket brigades, but institutional bodies established to represent the interests of affected citizens have, themselves, to build and maintain the confidence of the wider community. A comment made by the Mayor of Soulaine-Dhuys in France, who referred to the Aube CLI 'waking from its torpor' and gaining in credibility in the process, tells us implicitly that such bodies, particularly over time, may come to be seen as passive and ineffectual.

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[32] This point was also raised in the course of the third UK workshop on monitoring and retrievability (UK CEED 2002: 16). As another example, Canadian communities unhappy with the handling of wastes in the uranium mining region of Elliott Lake established a Standing Environmental Committee (SEC) in an effort to develop the capacity for monitoring and research that involved the community (MacDonald in NEA 2003: 107-111). Despite 45 years of experience of mining in the area, there was a low level of confidence in the regulators and site operators. Although earlier community monitoring initiatives had been short-lived, the SEC aimed to reassert the role of the local community in a number of ways including organising conferences on waste management technologies, compiling a repository of waste management information, and calling for public visits to the sites to be reinstated.

A visibly active role for stakeholders' representative bodies may therefore be important for confidence at all levels.

3.5.3 Stakeholder Capacity to Participate

Several of the studies of monitoring described in this section highlight the development of new capacities, including technical understanding and competencies, by citizens and community groups. They demonstrate therefore not only that some citizens and stakeholder groups may wish to become more directly involved in repository monitoring programmes, conceived in broad terms as the entire package of monitoring activities, but also that they are, in principle, capable of doing so.[33] This is consistent with a conclusion that emerged from an FSC thematic session on the link between RD&D and stakeholder confidence: 'Communities need to be informed and have the capacity to, *should they wish*, participate in monitoring as well as decision-making' (NEA 2006: 26, *emphasis added*). Reporting on a 2007 symposium on the safety case, a member of the NEA's Integration Group for the Safety Case Core Group was even more explicit than the 2006 FSC report. He maintained that 'a broad range of aspects of the safety case can be refined with the help of local stakeholders' and that 'local (host) communities [...] can develop technical capability with proper support', going on to assert that 'testing and monitoring programmes *by local communities themselves* can enhance confidence and trust in the project' (Strömberg, in NEA 2008: 21, *emphasis added*).

3.5.4 Institutional Control and Stakeholder Participation

The evidence reviewed in this section does not support generalisations about the form that community engagement with monitoring activities might take or about stakeholder views on 'post-closure' monitoring, particularly given national differences in political culture and in attitudes towards and confidence in geological disposal (TNS Opinion & Social 2008).[34] Nevertheless it does appear that, notwithstanding technical expert

[33] It is noteworthy from the examples identified here that universities and local higher education colleges often play an important role in community monitoring programmes, either by being delegated the responsibility of conducting the monitoring, as in the case of Carlsbad and the WIPP, or by acting as partner or technical adviser, as in several of the other cases (the role of universities in community monitoring is discussed explicitly by Savan *et al* 2003). This can be attributed to the greater trust that is often expressed by citizens in academic scientists than in other sources of information about technological risk (see, for example, TNS Opinion & Social 2008).

[34] There may, of course, also be differences in the degree of emphasis or attention which has, to date, been given to the role of monitoring in different countries. It is notable, for example, that whereas some reports of FSC workshops contain many references to monitoring, this is particularly the case where monitoring is an explicit component of a repository programme, as in the French case, or has been a significant focus of stakeholder interest and activity, as in the Hungarian case. When workshops have been hosted in countries where monitoring does not feature so prominently, as in Germany or Sweden, there has been correspondingly little mention of monitoring in the report, despite the international attendance at these events. For example, the report of the

confidence in the robustness of geological repositories designed to achieve passive safety, many stakeholders expect institutional oversight and control to continue for an extended, if unspecified, period of time after operations have ceased and, in several countries at least, for stakeholders themselves to be involved in some way in monitoring activities and decision making (e.g. UK CEED 2000; NEA 2003; NEA 2010b). A recent statement published by the NEA's Radioactive Waste Management Committee acknowledges that '*adequate institutional control is an essential condition* for assuring confidence in the safety of a national waste management undertaking' and that, although this must be exercised by the safety regulator, '*a measure of control may also be delegated to other parties*', noting that 'shared control is viewed as important by regional and local stakeholders' (NEA 2012a: 14, *emphasis added*). In support of this statement the NEA RWMC cites survey research conducted in the USA on public confidence in the safety management at nuclear power plants, which found that the single thing which citizens said would increase their trust would be that 'an advisory board of local citizens and environmentalists is established *to monitor the plant* and is given legal authority *to shut the plant down* if they believe it to be unsafe.' (Slovic 1993: 678, *emphasis added*). Notwithstanding the difference in the basis of nuclear power plant safety and that of a geological repository, the point here, one supported by several of the examples given above, is that it is not just involvement in monitoring that underwrites stakeholder confidence but also the assurance that the capacity exists to take action in response to any unexpected or adverse results and to ensure that there is effective *control* of the hazard. It is therefore important to sound a cautionary note on the conditions under which stakeholder involvement in monitoring may sustain confidence in a geological disposal facility.

The problem is highlighted in a study by Noble and Birk (2011) who, following their study of community-based monitoring associated with uranium mining in Saskatchewan, question whether it had done anything *more* than bolster confidence and improve relations. Their study cautions that, in some cases at least, such activities may amount to no more than what they characterise as *comfort monitoring*, which is not integrated with institutional mechanisms for decision making and taking action and so may have no material impact.[35] Many of the cases of participatory monitoring

workshop held in Östhammar, Sweden in May 2011, entitled "actual implementation of a spent nuclear fuel repository in Sweden", contains virtually no reference to monitoring. It is only during a discussion on 'value added' approaches to community development that an unattributed comment on the subject is made: *"monitoring facilities which help people living in the area to feel safe and under control can be considered added value and at the same time, become a means for openness and transparency*" (NEA 2012b: 24).

[35] Noble and Birk's use of the phrase 'comfort monitoring' points to the sense of public 'reassurance' as a potentially manipulative use of monitoring, something that NGO participants in a UK workshop on monitoring and retrievability were very concerned to discourage, as opposed to the more neutral notion of 'assurance' typically adopted in relation to expert uses of monitoring (UK CEED 2000). Although Noble and Birk's

programmes at radioactive waste management and disposal facilities do not appear to have yet been studied with this question in mind, something that would require a longitudinal research design in order that the effects over time of such a programme could be evaluated. The evidence already indicates that, in the short-term at least, stakeholder participation in monitoring programmes may have the desired effect of reducing levels of stakeholder concern within community settings and reduce the likelihood of conflict with implementers or regulators; however, should it later become apparent to stakeholders that participation in a monitoring programme is inconsequential or ineffective then, past research would suggest, some at least may become cynical and distrustful of the organisations and institutions involved if they come to perceive the process as tokenism or manipulation. This is a useful reminder of the need for all parties to be explicit about roles and expectations, and equally for all concerned to maintain a suitably critical perspective on any claimed benefits of citizen participation.

One important conclusion that can be drawn from the social science research and other reports reviewed in this section is that, when considering its potential contribution to building public confidence in the long-term safety of a geological disposal facility, repository monitoring needs to be set in the context of the overall monitoring programme. During the operational phase of a repository, at least, it seems likely that stakeholders will expect a comprehensive programme of monitoring that includes not only monitoring of repository system conditions and evolutions but also of environmental and socioeconomic conditions, changes in which might be attributable to the presence of a repository. Each of these different types of monitoring may be required by different agencies and subject to different regulations; some additional monitoring may be required by affected communities in order to provide transparency and, perhaps, assurance. It may be that overlapping requirements introduce redundancy into the monitoring system. It has been argued, for example by an expert stakeholder participant in a UK workshop on monitoring and retrievability (UK CEED, 2000), that environmental monitoring for the presence of radionuclides was unnecessary as direct monitoring of repository processes would identify any failure of containment long before radionuclides migrated into wider environmental systems; nevertheless, a certain amount of redundancy may be called for not only to meet different regulatory requirements but also community stakeholder requirements. Given the examples outlined above of local stakeholders insisting on conducting monitoring activity

observations are based on a single case study, Conrad and Hilchey (2011) note that many groups participating in environmental monitoring projects found that their data were not actually used. The problem of tokenism has been recognised – and criticised – in the field of participation research at least as far back as the seminal paper by Arnstein (1969).

independent of that conducted by site operators and regulators, it is conceivable that in some contexts affected stakeholders may have monitoring requirements additional to those of regulators. They may find it reassuring that there is not only what has been referred to as 'defence in depth' in the form of a multi-barrier repository design but also what might be termed 'surveillance in depth', where not only sensor redundancy but also multiple parameter monitoring ensure as much useful information as possible on barrier performance and on the performance of the repository system. The implications of the themes of sustained surveillance – or vigilance –, trust and transparency that have been outlined in this concluding part of Section 3 are discussed further in Section 4 of the report.

4 Monitoring: a Combined Technical and Social Activity

This section reflects on the technical and social aspects of monitoring and on the issues the authors think are important if monitoring is to become an instrument that can effectively contribute to assuring all parties concerned of the safety and reliable performance of a deep geological repository.

From the interactions we had with technical experts (see Section2), it became clear that the expert community recognises that monitoring has both technical and social purposes. While there are strong technical reasons why one should monitor a geological repository (e.g. monitoring of disturbances in the host rock during excavation; or monitoring the lining of access galleries in the period before closure in repositories in salt or indurated clay geologies), questions of evidence, confidence and decision-making always have, to a greater or lesser extent, a social component. In what follows we try to unravel some of these socio-technical entanglements and the issues that they raise.

In Section 4.1, we do this by looking at the close link between monitoring and safety, as monitoring is considered a key factor in providing confirmation about the safe performance of the repository system. The experts tend to focus here on the operational and pre-closure stages. However, as some of the examples in Section 3 indicate, concerned citizens and decision-makers may look at things from a different perspective and wonder how one can ever be sure that passive safety is guaranteed without some continuous form of monitoring? We will consider this challenge by looking at monitoring as vigilance.

But safety is not only about getting the numbers right. As Section 3 demonstrates, it is also about interpreting what the numbers mean, and about being able to put trust in, or at least have the ability to exercise some form of control over, those providing and those interpreting the numbers. Therefore in Section 4.2 we address the question of trust in relation to the practical organisation of monitoring.

Subsequently in Section 4.3 we examine how this affects roles and responsibilities in monitoring, and the question of what to do with the data and how to interpret results. We reflect on these issues in relation to the potential for monitoring to contribute to transparency. Finally, in Section 4.4 we draw conclusions on the implications this has for the potential of monitoring to contribute to building public confidence in a repository system.

4.1 Monitoring as Vigilance

Essentially, geological disposal and the concept of passive safety envision the permanent isolation of radioactive waste from society: its placement outside of the biosphere in perpetuity. This has often been criticised as the adoption of an 'out of sight and out of mind' mentality, with the underlying concern being that a lack of oversight after closure would result in any unanticipated threats to safety that might subsequently develop going unobserved and unchecked. Choosing not to maintain societal memory of the location of a repository (i.e. permanently locking the waste away and then 'throwing away the key') rather than continuing to remind ourselves of the buried presence of radioactive waste could be one way of reducing the likelihood of future human intrusion (see, for an example, Barthe 2009: 124). However, the prevailing paradigm would seem to be one of keeping alive the memory of the location and harmful nature of waste repositories, in order to deter future generations from inadvertently breaching the containment through mining or other activities. [36] This approach has been strengthened by even greater concern with monitoring and safeguarding nuclear materials by safety authorities and international organisations such as the IAEA amid heightened fears of global terrorism in the aftermath of 9/11. Furthermore, both in specific national policy contexts and in international fora such as the NEA, we see the question of retrievability/reversibility in waste repositories receiving sustained attention, together with a growing awareness that, even in countries where retrievability or reversibility are not part of official policy, implementing geological disposal is something that will imply several decades of emplacement activity, during which nuclear materials may be relatively accessible.

Geological disposal should therefore not be characterised as a process of institutional forgetting, but could be compared to the establishment and maintenance of a high security prison, from which no inmate is ever expected to be set free again. Monitoring is in this respect important in view of a constant need for staying alert, of providing checks and balances, but also of assessing risks and providing some guidance in case unexpected things do happen. In other words, monitoring can be seen as the effective means to put a guiding principle of vigilance into practice. Again, we refer here to monitoring in a broader sense (see Section 3), not restricted to monitoring repository

[36] The social and institutional arrangements required to support this have been the focus of research in the USA and elsewhere for more than two decades (e.g. Hora et al 1991; Hora and Von Winterfeldt, 1997). More generally, this is expressed not only in institutional arrangements but also in the intuitive responses of ordinary citizens to the concept of phased geological disposal, as the following observation from the report of a focus group study of the attitudes of British citizens illustrates: 'Most respondents were disturbed by the idea that there would ever be an end to human management. They argued that monitoring should continue for as long as the waste exists' (Future Foundation 2002: 16).

and near field processes, which is the focus of the technical research in the MoDeRn project.

In this section, we look at how monitoring as the pursuit of vigilance, of continuous awareness of the presence of radioactive material, even if several hundred meters below the surface, is an important element in thinking about nuclear safety.

4.1.1 Weinberg's Vision of Nuclear Safety as Vigilance

The idea of vigilance as a leading principle for nuclear safety is not new, and has long since had advocates within the nuclear expert community. A famous principled vision, outlining the challenge of the safe disposal of radioactive waste and how it should be addressed, was provided by the nuclear scientist Alvin Weinberg. This vision referred to a need for both technical and institutional innovation. Writing at the beginning of the 1970s, at a time when public concerns over radioactive waste, and nuclear safety more generally, were becoming more widespread, Weinberg identified a 'Faustian bargain' as having been struck between the nuclear sector and society at large (Weinberg 1971/1992). What he and others saw as a cheap abundant new source of energy came at a price: the unusual degree of *vigilance* which of necessity had to be exercised over all programmes of nuclear power generation during the entire course of their development in order to guarantee safety (Weinberg 1971/1992: 234).

Somewhat misleadingly Weinberg, writing during the Cold War years, drew a direct parallel between the vigilance required to protect peaceful nuclear energy and that already exercised by what he characterises as a 'military priesthood' in order to protect against an inadvertent use of nuclear weapons that might precipitate nuclear war. This made it easy to associate the 'eternal vigilance' of which Weinberg spoke with a small elite cadre wrapped in secrecy, and hidden away from society at large. While the formation of such an isolated and publicly invisible 'priesthood' has been stronger in relation to the monitoring of nuclear weapons during the Cold War, it has arguably never been an appropriate option for exercising vigilance over peaceful nuclear energy: the military origins of civilian nuclear development have coloured perceptions of its legitimacy and to some extent continue to do so to this day.

Towards the end of his life Weinberg was at pains to point out that his notion of a 'Faustian bargain' had often been misunderstood (Spreng, Marland and Weinberg 2007). What was distinctive about the type of vigilance he had in mind, was its **constant and tireless nature**, not its elitist and backroom character. The very survival of the nuclear sector should in this respect be understood as perpetually on the line in its tireless, unceasing and painstaking efforts to maintain nuclear safety. Extending this vision to reflect the specific characteristics of nuclear materials, Weinberg also emphasized the exceptional longevity of vigilance that he saw as being necessary to guarantee safety.[37]

Already in 1971, he could identify 'two basically different approaches' to the the safe disposal of radioactive waste: permanent above-ground storage versus geological disposal. These two approaches entail very different commitments – and underlying 'philosophies' – which continue to be debated by stakeholders today and have a bearing on the MoDeRn project. Above-ground storage of wastes in 'concrete vaults', Weinberg (1971/1992: 234) proposes, calls for an enduring technological 'priesthood' to monitor and, as necessary, to manage the wastes and the facility.[38] The relative advantage of geological disposal in Weinberg's eyes was, therefore, the progressive relaxation of monitoring demands it appears to allow for as a more complete isolation of the waste from the biosphere is secured. Nevertheless, he still saw a residual amount of surveillance being required 'in perpetuity' to prevent human intrusion into the facility.[39]

4.1.2 Monitoring as an Enactment of Vigilance

By defining vigilance as the first principle of nuclear safety, Weinberg provided the field with not only a sense of purpose, but also a moral form. Nuclear safety obliges society to be tireless, and always alert to possible danger. This is particularly the case for nuclear installations such as power plants, fuel production or reprocessing plants, and storage facilities. Deep geological repositories may be in that respect distinct from other nuclear activities, as their goal of establishing a state of inherently passive safety can be understood as a way of trying to renegotiate the need for 'eternal' vigilance. But in so far as this holds (and this is at the heart of the debate today), it can only be argued for the situation after closure. Throughout the operational phase (including any extended pre-closure phases), the situation remains more comparable to other nuclear facilities.

Staying alert and vigilant calls for the continuing refinement of powers of observation. Etymologically speaking, vigilance and monitoring point to common concerns. Monitor derives from the Latin *monere* 'to remind, warn' and is closely associated with *admonere*

[37] For other reflections upon the implications of the long-term relationship between stakeholders who host a disposal facility and the waste, see O'Connor (2003) and Pescatore and Mays (2008).

[38] This notion of a 'priesthood', as a cadre maintained over the generations to ensure persistence of institutional and societal memory and the necessary expertise, was also espoused by Thomas A Sebeok in a report commissioned by the US Office of Nuclear Waste Isolation (Sebeok 1984).

[39] Weinberg's reference to a time span that was 'in perpetuity' seems never to have been made very explicit but his references to civilizational timescales indicates a duration that far exceeds generational or even historical human timescales, being related to the persistence over millennia of the hazard presented by some radionuclides. Weinberg's phrase may be in that sense seen as a rhetorical device, intended to convey the burden of responsibility to which he was alluding.

‘to warn earnestly’, or ‘to reprimand’. Therefore, monitoring has never simply been a matter of measuring or verifying things, it has always implied a concern with the maintenance and enforcement of proper order. The original monitors, dating back to the 1540s, were senior pupils at schools entrusted with maintaining discipline. This implied a delegation of authority to some pupils in order to gain the compliance of others. In more recent times, a monitor has also come to refer to a technical device used to measure the performance of other technical devices. In another evolution of the usage of the word, a monitor has also come to mean a technology for producing new forms of visibility: for example, the device that displays the picture from a CCTV camera, from industrial ultrasound equipment or from a magnetic resonance imaging device that makes the interior workings of the human body visible. In this way monitoring has become associated with the production of transparency, and of faithful accounts or mirrors, of behaviour and action. We must however keep in mind that monitoring is not just about showing reality as it is. It is also about interpreting collected data and giving meaning to these results, and hence about a process or action of producing reality.

With respect to geological repositories, this role of monitoring as an enactment of vigilance is most pertinent when addressing monitoring for operational safety (for example, radiological monitoring for the health of workers or monitoring the structural integrity of ground support) and environmental impact (for example, monitoring groundwater quality, air, soils, or fauna and flora for any evidence of environmental impacts). Monitoring with respect to operational safety, is in first instance about questioning safety: Have all necessary measures been taken to protect the workforce? What impact will the introduction of new emplacement techniques have on underground working conditions? Here the appreciation of what monitoring can and should contribute is not likely to vary too largely between experts and lay-stakeholders, in particular concerned local citizens.

Where long-term safety is concerned, the link between active monitoring (particularly in the near field) and the need to remain vigilant may become a bit more relaxed. From a technical specialist’s point of view the focus of monitoring for long-term safety during the operational and, more particularly, the pre-closure phase is on confirming safety, rather than questioning safety: Can monitoring results support the technical and scientific basis used to evaluate long-term safety and the transition to passive safety? Can monitoring reduce uncertainty and confirm or even enhance the knowledge base? ‘Eternal’ vigilance in regard to a closed and passive geological repository is from a technical expert perspective about ensuring that the facility remains isolated from humanity and its environment, and deterring human intrusion. Monitoring as an expression of vigilance in a post-closure phase is mainly about observing changes in the repository environment and considering possible effects these may cause on the repository function. Despite the detailed catalogue of features, events and processes considered in the design and performance assessment of a repository system, there was acceptance among the experts that we interviewed that it is not possible to plan for all contingencies, although they tended to focus on contingencies external to the system. When considering the post-closure phase and the safety case there was less consideration given in the interviews to unanticipated contingencies within the repository system.[40]

However, for those in society who may have less faith in modelling and statistical predictions of long-term repository behaviour, remaining vigilant both before and after closure of the repository is likely to mean something slightly different: making sure at all times that the repository will not have any effect on its natural and social environment, and maintaining preparedness in case the unexpected should happen.[41] Such an interpretation of vigilance would seem to be more in line with a view of monitoring in terms of 'checks and balances' that question, or at least critically assess safety.

4.2 Putting trust in a monitoring system

For monitoring to be able to contribute to a better public understanding of and greater confidence in the repository system, a relatively high amount of trust in the monitoring system will first and foremost be required.

In the following paragraphs, we will explore why there is a problem of trust as regards to geological repositories (4.2.1), what exactly we mean by the notion of 'trust' (4.2.2), and how general insights into trust relations between experts and lay people contribute to our understanding of trust in relation to monitoring systems (4.2.3). In this section we will focus on monitoring in view of long-term safety: firstly because that is the primary objective of other research activity in the MoDeRn, and secondly because we see that aspect to be the most troublesome when it comes to addressing different stakeholders' expectations and establishing relations of trust.

[40] This may have been due to the focus of the interviews as, in addition to their work within the MoDeRn project, some of these experts had previously participated in projects that were working on the safety case, such as the European Commission's PAMINA project.

[41] This conjecture draws both on the research on risk and trust and on the evidence outlined in Section 3 of this report, which makes clear that in many situations stakeholders require not only operator and technical expert assurances of safety but the additional reassurance of (independent) monitoring for any evidence of exposure to harmful releases. In the case of geological disposal, of course, it is expected that nothing will be released and therefore no changes could be observed for tens of millennia, which could well mean that future generations of stakeholders decide to abandon the practice within the two to three centuries or so for which post-closure monitoring is currently anticipated in those countries where it is being proposed. Nevertheless, in the first instance it seems reasonable to anticipate this as a likely stakeholder expectation and requirement.

4.2.1 A Geological Disposal Facility = an Environmental Risk

Dealing with radioactive waste is undeniably a hazardous activity. If not, we wouldn't have to go through the trouble of protecting man and the environment from it. The risk of possible contamination is obviously higher when the waste or waste containers are being handled. That risk will be far lower as long as the waste is isolated and contained without anyone coming near it. The whole concept of geological disposal is based on the idea of isolating the waste from the biosphere for as long as possible. However, it is clear that no engineered barrier will last long enough to prevent the radiation from 'leaking out' at some point in time. Therefore the concept of geological disposal is based on multiple engineered and natural or geological barriers, where different barriers work together in combination. The expert community is convinced that this is the best way of guaranteeing that radio toxicity levels will have decreased enough before any radionuclides escaping a geological repository would ever come in contact with the biosphere. Experts base their judgement on scientific knowledge drawn from research and on experience generated through expert systems.

However, concerned citizens, the public and public decision-makers may not share this conviction. From their point of view a geological disposal facility is considered a potential environmental risk. This we also see reflected in environmental legislation: e.g. Annexe I of the EIA directive[42] explicitly lists *'Installations designed for the final disposal of radioactive waste and irradiated nuclear fuel'* as projects that must as a rule be subject to systematic assessment because of their significant effects on the environment. Compliance monitoring for environmental impact assessment will in this regard be important. But will this be enough? One of the multiple reasons why there tends to be a demand from society for some form of reversibility, or at least flexibility, in the concept of geological disposal, is that people value the existence of a 'Plan B' in case anything goes wrong. The public may therefore not be as confident that with today's knowledge, experts can fully understand and control long term repository behaviour.

These doubts have many origins, but are at least partially based on evidence from known cases of disastrous sociotechnical failures (Irwin 2001[43]; Jasanoff 1994; Perrow 1984). The accidents at the Three Mile Island, Chernobyl and Fukushima-Daichi nuclear power stations have added to the stock of negative cultural imagery that in popular culture is often associated with nuclear technologies. Weart (2012) has characterised this as contributing to 'nuclear fear', while other researchers have pointed to the

[42] COUNCIL DIRECTIVE of 27 June 1985 on the assessment of the effects of certain public and private projects on the environment - 85/337/EEC - OJ L 175, 5.7.1985, p. 40.

[43] "… public groups can be expected to bring more than blank sheets of paper to environmental debate: **memories of previous incidents**, moral judgements and forms of local knowledge can all play a part in local understandings of environmental issues and in the very construction of those 'issues'." (Irwin 2001: 96)

stigmatised nature of nuclear technology in popular culture (e.g. Flynn 2003). However, although the work of Weart and others usefully draws attention to the potential influence of nuclear imagery, an emphasis on emotional response fails to recognise the ways that people draw on evidence of failures of expertise, of technological systems, and of regulatory and organisational risk management to make judgements about assurances of safety with which they are being presented (e.g. Freudenburg 1993). These events are often presented by the industry as being in important ways 'exceptions' but each in its way provides evidence not only of the 'man-made' nature of technological disasters but also of the complex sociotechnical conditions that have led some analysts to talk of 'normal accidents' (Turner and Pidgeon 1997; Perrow 1999). They have therefore come to represent the capacity for catastrophic failure, even in what are typically presented as high-reliability organisations and industries, so it is perhaps unsurprising that we find these events, although related to the operation of nuclear power plants, being used as analogies and reasons for caution when radioactive waste management is being discussed with members of the lay public (e.g. Hunt and Simmons 2001).

Similarly, the case of the German Asse Mine, where the inflow of brine has raised concerns about possible flooding and collapse of the salt, and consequently the safety of the LILW stored there, is likely to have a negative impact on how some citizens and stakeholder groups perceive geological disposal. Even if there are good explanations for the problems at Asse and why this could never happen in a real geological disposal facility, those concerned may not necessarily trust this message. The fact that the problems at Asse have been attributed as much to political-administrative factors as to the geotechnical problem that resulted in water flowing into the mine highlights the interplay of social and technical elements in producing a public issue. Furthermore it is not only risks due to negligence that gives rise to public discomfort about the safety of repository facilities. What concerns many people as much as, if not more, than the fact that there remain risks due to the impossibility of foreseeing all contingencies, is when uncertainties are not publicly acknowledged. Expert statements on repository safety that do not acknowledge the remaining uncertainties may therefore not be perceived as trustworthy (Irwin 2008).

4.2.2 Trust Relations between Experts and Lay Citizens

The risks of radioactive waste are an example of a type of risk that has emerged in the modern industrial period. They are characterised by German sociologist Ulrich Beck (1992; 1995) as being: (a) undetectable to our physical senses and therefore only discernible through technical instruments and scientific judgement; (b) not limited in their effects by time, space or social differences; (c) the result of human intervention in nature, and thus attributable to decision-making; and (d), because of their complexity, not to be grasped by the usual rules of causality and liability, and therefore not amenable to risk management mechanisms such as insurance. Although one might take issue with some of the detail of Beck's characterisation, a first point to note here is that, being unable to rely on sensory data to evaluate risk, citizens are placed in a relationship of dependency on experts and expert systems (Giddens 1990; 1991); a dependency that, as discussed below, makes trust both extremely important and at the same time contingent upon other aspects of those relationships. A second point to note is that this is compounded by what Giddens (1994) has referred to as the problem of 'manufactured uncertainty': the more knowledgeable we are about the social and natural world, the more their complexity is revealed. While on the one hand this offers us both individually and collectively more opportunities and possible options for the future, on the other hand it makes us more aware of the risk potential and the uncertainties involved when choosing one option over another: 'there are no longer clear paths of development leading from one state of affairs to another' (Giddens 1994: 185). The increasing complexity of society and of our systems of knowledge has led to an increased division of labour and hence to greater dependency on technical experts to identify and assess environmental and technological risks for the benefit of the broader society. This comes at the cost of a substantial increase in the vulnerability of 'the very interdependencies that also make the system work' (Freudenberg 1993: 914).

It is here that the problem for science and technology occurs: as many commentators have noted, when it enters the public and political spheres, science often faces challenges to its credibility and public authority, with the public trust in scientists and in expertise that is often recorded in relation to 'science-in-general' becoming more critical when contextualised in the particularities of specific sociotechnical issues.[44] This can be attributed to an on-going pluralisation of technical and scientific knowledge claims and increasing lay awareness that science is always value laden and rarely offers unanimous estimations or judgements (Ali 1997). This quality can in turn lead to science becoming politicised in public controversies and being used as a 'weapon' by protagonists in such disputes (Eyerman and Jamison 1989; Beck 1992). As a consequence, it has been argued, scientific knowledge is losing its 'nimbus of objectivity, of social neutrality and of reliability' and in itself becomes a source of uncertainty (Lau 1992: 243). In today's society, science is no longer [seen as] a more legitimate activity than many other social activities (Lidskog 1996). In spite of this, on a general level, science may still have social authority, and scientific knowledge still is generally perceived as having some predominance over other forms of knowledge (Lidskog 1996). Opponents against geological disposal for example reproach waste managers and decision-makers for letting other than scientific criteria prevail in the process of site selection (e.g. Wallace

[44] For a discussion of this distinction in relation to lay understandings of science, see Michael (1992).

2010). Empirical research has furthermore shown that it is not the knowledge or science as such that is trusted or distrusted, but the institutions that produce them (e.g. Wildavsky and Dake 1990).[45]

4.2.3 Conceptualising Trust, Trusting Institutions

Before addressing further the how this affects (or could affect) the issue of geological disposal and how that links up to monitoring, we need to look more closely at the concept of trust itself. Trust is an essential component of any enduring social relationship: 'without trust, the everyday social life which we take for granted is simply not possible' (Good 2000: 32). One reason for this may be that it performs the social function of reducing the burden imposed upon us by complexity, enabling us to take some things as given (Luhmann 1979). However, another aspect of contemporary existence is our awareness today that society is formed by human agency. Since we have little control of other people's actions we cannot have full control over our social environment; we therefore need to rely on trust (Giddens 1990; 1991). Trusting in that respect then becomes 'the crucial strategy for dealing with an uncertain and uncontrollable future' (Sztompka 1999: 25).

Trust is in essence something we vest in people, not in natural objects or events: 'Even if we seemingly confer trust on objects, […] we in fact refer to humanly created systems and indirectly we trust the designers, producers, and operators whose ingenuity and labour are somehow encrypted in the objects.' (Sztompka 1999: 20) 46. When we put trust in people, we normally do not ask questions – trust is about not worrying and not asking questions. When we start asking questions, trust has to be repaired by the

[45] It is instructive to note that although 'scientists' were found by the 2008 Eurobarometer survey on public attitudes to radioactive waste to enjoy, along with environmental NGOs, the highest level of trust as a source of information (38 and 39% respectively), the questionnaire makes no distinction between scientists employed by different organisations and institutions, and that only 11% of the sample expressed trust in the nuclear industry (TNS Opinion & Social 2008). Research on other sociotechnical issues has repeatedly found that organisational setting can make a significant difference to public evaluations of trustworthiness, with 'university scientists' typically more trusted than those working in business organisations (e.g. Worcester 1999; Critchley 2008).

[46] Luhmann (2000) makes a further distinction between confidence and trust, noting that although both refer to expectations, confidence relates to situations where we do not consider the possibility of our expectations being disappointed, whereas trust always involves an awareness of the risk that those expectations may be disappointed as a result of the actions, or inaction, of others. This suggests that although the term 'confidence' is widely used when talking about the relationship of societal stakeholders to radioactive waste management, by this definition the word 'trust' is more appropriate. Although much of what has been written about trust concerns interpersonal trust, Sztompka argues that social trust is not fundamentally different. It is about putting trust in social roles, social groups, institutions, procedures, systems. But all these different types of trust operate according to the same logic and build on trust in people and their actions: 'We ultimately trust human actions, and derivatively their effects, or products.' (Sztompka 1999: 46).

answers given to these questions. And such questions can always arise and in every social setting. In this respect trust is never a given: to start asking questions means to start calculating about the future.[47]

Therefore Sztompka (1999: 25-26) defines **trust** as '**a bet about the future contingent actions of others**', involving specific expectations about how other persons will behave on a future occasion, and a form of commitment through action – the placing of the bet.[48] This commitment can be stronger or weaker, depending on the circumstances. Sztompka (1999: 28-29) identifies six kinds of circumstances that may impact a commitment of trust:

1) the consequences involved;
2) the expected duration of the trust relationship;
3) the (ir)revocability of the decision to place trust in someone;
4) the amount of risk involved, defined by the scope of possible losses in case of a breach of trust;
5) the presence or absence of insurance or other back-up arrangements against losses;
6) the value of the 'object' entrusted.

Trust is thus strongly linked to the notion of risk, and in particular risks evoked by human action. This is because we can define risk as the uncertainty about the future in terms of potential loss as a consequence, or perceived consequence, of a decision (Luhmann 1993). Being attributable to a decision (or to the lack of a decision) and thus to human action, is what distinguishes risk from danger. The notion of danger also refers to uncertainty about the future and potential loss, but without it being attributable to human action.

In the case of a geological repository we are clearly talking about a situation of risk, in which any uncertainty related to the future behaviour of the repository system (whether induced by human action, or natural phenomena) will be attributed to the very decision of building the repository in that particular way in that particular place. Implementing

[47] Under these conditions, trust itself is always provisional and contingent upon a potentially changing context, a condition which has been characterised, with some differences of interpretation, as 'sceptical trust' (Lewis and Weigert 1985), 'active trust' (Giddens 1991), 'conditional trust' (Jones and George 1998), or 'critical trust' (Walls *et al* 2004). It may in fact be more appropriate in many circumstances involving risk and government institutions or private organisations to think not in terms of securing trust but rather of a *suspension of distrust* that nevertheless maintains a healthy scepticism (Cook and Gronke 2005; see also Barber 1983).

[48] Sztompka's formulation of trust as a 'bet' therefore resonates with Weinberg's 'wager' (see also Section 4.3) in that the requirement implicit in Weinberg's vision is that, in a classic principal-agent problem, those delegated by society, his 'priesthood' institutionalising knowledge and expertise, with the task of exercising vigilance be trusted by those whose interests they represent.

geological disposal furthermore demands an extremely strong commitment of trust by those (potentially) affected by it, as for each of the six influencing 'circumstances' described by Sztompka, the impact (whether 'real' or 'perceived') is vast. Committing to host a high level waste repository is indeed not without consequences and implies more than a lifelong commitment. Given the characteristics of the waste involved, the stakes remain undeniably high and even if experts consider it highly improbable that something will go wrong, the possible impact if it should is difficult to foresee. As a consequence of this and of the time frames involved, no real contingency plans exist, and the possibility to withdraw from the commitment once the repository becomes operational diminishes considerably. [49] Last, but not least, the 'object' that is entrusted in making such a commitment is human life itself, something that, notwithstanding the valuations of insurers and economists, is considered by many people to be priceless[50]. The notion of reversibility can in this respect be seen as a way to soften the commitment, offering some form of insurance and suggesting a possibility of revocability, thereby rendering the commitment less final.

An additional complication here is that in the modern world individuals find themselves in all areas of their lives in *asymmetric* power relationships with organisations and institutions (and, one might add, systems of expertise) which are the locus of key decisions that affect them (Coleman 1982). This is an unavoidable outcome of the social division of labour that results from increased specialisation and differentiation in complex societies. For individuals to trust such entities involves a different type of relation and different forms of assurance to those which obtain in their personal relations with other individuals; in other words a form of 'impersonal' trust (Shapiro 1987). One basis upon which such trust in the motivations and actions of organisational actors may be established is by putting in place formal institutional mechanisms, be they mandatory or voluntary, that provide assurances, checks and sanctions which increase the likelihood that those actions will meet societal (and individual) expectations (Zucker 1986; Simmons and Wynne 1993). We can see the organisational changes made by many radioactive waste management agencies over the past decade or so as attempts to institute such mechanisms and thereby not only to establish but to present to stakeholders such *trustworthy* characteristics as transparency and openness, qualities that were notably lacking throughout the nuclear industry in earlier decades (NEA 2007c).

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[49] Something which for many raises concerns about problems resulting from technological inflexibility and the irreversibility of decision-making commitments that have so often been associated with complex, large-scale infrastructural projects (Collingridge 1992; also Flyvbjerg *et al* 2003 for other problems).

[50] Sztompka himself considers the sixth circumstance a specific one, in which a particular object (for example, a child) is given into the care of another person or persons (Sztompka 1999: 29). This entrusting of 'an object' into someone's care may also be of a more symbolic nature, however, where the 'object' is not yet present, as is the case with future generations who might be affected by any failure of a geological repository.

This excursus on institutional mechanisms for building trust is therefore of specific importance if we want to understand the extent to which monitoring and the information that it produces could influence the public's confidence in a geological repository system. Trust in a monitoring system is not only, and perhaps not even primarily, to do with the results it produces: it is to a large degree related to how the monitoring system is set up and operated, and by whom.

4.3 Institutional Context: Roles, Responsibilities and Transparency

This leads us to the question of who plays which role with regard to monitoring and how monitoring results are interpreted and presented. For a good understanding, we focus here on the organisation of monitoring itself, as the question we want to address is how monitoring can contribute to building and maintaining confidence in a repository system. However, trust and confidence in the repository system as a long-term solution for managing radioactive waste, have many other influencing factors. In this section, we consider only those issues relating directly to monitoring within the context of geological disposal.

Returning to Weinberg and his concept of vigilance, it can be argued that, in retrospect, the most interesting ambiguity remaining in his notion of a Faustian bargain or wager[51] is the question of **who is cast in which role?** As already implied, it might appear as if it is the nuclear sector which is making the wager that they can be relied upon to uphold their safety vigil for as long as needed, come what may. On the other hand, as pointed out by Berman (1983: 85), this may constitute a serious misreading of Weinberg's vision. Rather, he can be interpreted as affirming that it is society that is cast in the role of Faust, and the nuclear sector as Mephistopheles. It is society at large that is being lured by the beguiling bounties of nuclear energy, and that must assume ultimate responsibility for guaranteeing the existence of the 'eternal vigilance' upon which

[51] In one of his last publications, Weinberg and his colleagues return to the original text by Goethe to clarify that it is actually a 'Faustian wager', rather than a 'bargain', that best captures the nature of the professional ethos they wish to establish as the foundation of nuclear safety. Re-reading Goethe, they note how Mephistopheles is convinced that if he renders life on Earth sufficiently easy, then the virtuous Faust will grow careless and slothful. In response, Faust wagers:

If e'er upon my couch, stretched at my ease, I'm found,
Then may my life that instant cease!
Me canst thou cheat with glozing wile
Till self-reproach away I cast, -
Me with joy's lure canst thou beguile
Let that day be for me the last!
Be this our wager!

(quoted in Spreng, Marland and Weinberg 2007: 852) nuclear safety is founded. Supporting such an interpretation we find Weinberg connecting the institutionalisation of sufficient vigilance with two demands.

The first demand is that society be constant in its support of the skills and competences required to maintain vigilance:

> *"Quality assurance is the phrase that permeates much of the nuclear community these days. It connotes using the highest standards of engineering design and execution; of maintaining proper discipline in the operation of nuclear plants in the face of the natural tendency to relax as a plant becomes older and more familiar…in short, of creating a continuing tradition of meticulous attention to detail."*
>
> *(Weinberg 1971/1992: 235)*

The second demand, however, is not so clear-cut. This is because Weinberg is not willing to specify it himself, but only to identify the need for its specification: **How much vigilance is enough vigilance and how should it be organized?** According to Weinberg, this was *not for nuclear people alone to decide*. It was something that society at large had to be active in determining:

> *"We claim to be responsible technologists, and as responsible technologists we give as our judgement that these probabilities [of serious accident] are extremely – almost vanishingly – small: but we can never represent these things as certainties. The society must then make the choice, and this is a choice that we nuclear people cannot dictate. We can only participate in making it."*
>
> *(Weinberg 1971/1992: 236)*

The introduction of a requirement for retrievability in Swiss law on radioactive waste disposal[52] and for reversibility in French law[53], in each case putting a specific time frame on it, are examples of society deciding how much vigilance it expects. Experts, the 'responsible technologists' Weinberg refers to, are now expected to make suggestions on how to organise such vigilance (among others through an adapted monitoring programme). In France, these suggestions will subsequently be put to a public debate, before the public authorities will take a decision on the practical implementation of the principle of reversibility[54].

Monitoring, it would seem, could play an important role in aiding society to make decisions on how much vigilance is deemed enough. It is a means of verifying if implementers are indeed achieving the statutory safety levels they are aiming for. So who then should have the responsibility to organise a monitoring programme?

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[52] Nuclear Energy Act of 21 March 2003 (*Kernergiegesetz, vom 21. März 2003*).

[53] Radioactive Materials and Waste Planing Act of 28 June 2006 *(Loi n°2006-739 du 28 juin 2006 de programme relative à la gestion durable de matières et déchets radioactifs)*.

[54] National plan on management of radioactive materials and waste 2010-2012 *(Le Plan national de gestion des matières et des déchets radioactifs - PNGMDR)* : http://www.asn.fr/index.php/S-informer/Dossiers/La-gestion-des-dechets-radioactifs/Le-cadre-reglementaire/Le-Plan-national-de-gestion-des-matieres-et-des-dechets-radioactifs-PNGMDR

4.3.1 Who Should Act as Monitor?

There seems to be a general assumption that it is the responsibility of the implementer or responsible radioactive waste management agency to provide a monitoring programme for its repository facility. Such a programme provides implementers with a tool for continuous learning and an indication of how they manage the steps between the start of construction and final repository closure. At the same time, it helps them to demonstrate they have their repositories under control.

Monitoring has therefore both an inward-directed expert role and outward-directed societal role: its use to verify the models that provide the basis for long-term safety offers waste management agencies a means of becoming more self-observant; simultaneously it gives them a means to become more open and transparent to society, providing information to regulators, decision makers and concerned citizens. Establishing a legal obligation to monitor, as in Switzerland, or making it a regulatory licensing condition, as in Finland, institutionalises the role of monitoring as a tool for transparency and societal oversight. This would seem an important step if monitoring is to play a part in public confidence building.

But, monitoring can only provide public confirmation that nuclear safety is indeed being successfully upheld if society can trust the monitor, or by default trust the institutions responsible for supervising the monitor. Even if today we were living in a society where general trust in the nuclear industry and in radioactive waste management agencies were universally high[55], that would not be a guarantee that such levels of trust would persist for the next century (assuming that to be about the time until a decision on closure might be expected). Additional mechanisms therefore need to be in place to assure the monitoring system as a whole could be regarded as trustworthy, both by this and future generations.

Most crucial in this is to make sure the implementer is not the only party who has 'monitoring responsibilities', and that there are different parties involved in the development, installation, operation of monitoring devices and the analysis of their results. Or as one of the experts interviewed put it:

> *"I can vividly imagine people will say: 'Sure we think you should monitor, but we do not want just you to produce these devices, install and analyse them'. And if I'm really bad, if I were them, I would ask at least for a guarantee on the production and emplacement of any sensors (for if you put them where there is*

[55] Risk perception research continuously concludes that this is not the case. Although differences occur between countries, the general trends are similar. Results from a U.S. national survey for example showed that only 30% of respondents had 'quite a lot to a great deal' of trust in the nuclear industry, as compared to 54% for national environmental groups and 74% for university scientists (Whitfield et al 2009: 431).

nothing to see, well, then you will evidently not measure anything), as well as for some form of independent oversight and inspection. These are things that are likely to become issues of negotiation." (Respondent 5)

This avoids a situation of potential self-regulation and of implementers becoming the judges of their own case. This goes for different types of implementers, both those with a (semi)public character and those that are private entities set up by the nuclear industry.

The role of an independent regulator is in that regard an important one. Designing and implementing monitoring technologies is one thing, but who is interested in looking at the results of monitoring? For monitoring technologies to assist in building public confidence in the repository system, they must be political technologies capable of winning an audience. The regulator by definition plays an intermediary role between the implementer and society, and can be an additional source of trust. In an ideal world, there would be strong and competent regulators, working independently from the implementer, and guaranteeing to defend the overall good of society at all times. In the real world, this may not always be the case (e.g. due to limited state resources, too strong a bond between those responsible for policy making and those regulating and supervising it, …), or at least not necessarily perceived as such. Adding further components to the socio-technical arrangements that make up the totality of the monitoring system that could contribute to public trust, today and in the future, could therefore be considered.[56] As we saw in some of the examples outlined in Section 3, this could consist of: introducing (independent) oversight bodies to complement the work of the regulator, or to offset any deficit in trust in the regulator's performance of its activities where that has an effect on public confidence; offering concerned stakeholders the means to organise 'independent' reviews of monitoring activity; engaging concerned stakeholders to some extent in monitoring activity; and so forth. While such extensions of the arrangements for monitoring might in some contexts be felt by stakeholders to be completely unnecessary, the examples described earlier, from a wide range of settings, suggest that they can help to address stakeholder concerns where these exist and thereby contribute to building confidence in the system.

[56] This conceives of the 'monitoring system' not simply as a technical system that collects, analyses and represents data from the repository system, but also as including the set of institutional, organisational and social arrangements, activities and relationships within which this technical activity is embedded. When stakeholders evaluate a technological system they do not consider only the technology, but also the social context in which it is produced and operated, managed and mismanaged, and which provides the technology and its operations with meaning and purpose: in other words, as a socio-technical system.

4.3.2 Monitoring the Monitor: the Role of the Regulator

Even though radioactive waste managers today take the lead in setting up monitoring programmes and developing monitoring strategies, regulators are also considered key players in the monitoring system. First because they set guidelines and regulations on what they expect from a monitoring programme (already well-established for operational and environmental assessment monitoring, and in some countries currently under development for monitoring in view of long-term safety). Second because of their role in issuing nuclear licences and in maintaining oversight of the safety of all nuclear facilities under their jurisdiction. It is in that respect likely regulators will expect certain monitoring activities, some of which may become explicit license conditions.

Regulatory bodies or safety authorities can in that respect be considered as 'monitors who monitor the monitor'. Indeed, because of the complexity of the issue, the inexpert public is going to have to call on the services of those resembling scientific connoisseurs (Evans and Plows 2007: 832) of repository safety capable of advising whether elaborate sights and signs of safety should be accepted as warranting public belief. To a large extent this diverts the issue of trust to the relationship between the public and its regulatory bodies. Here society at large will be left hoping that their national safety authorities, as their scientific guardians of nuclear safety will be able to see through, and move behind, the accumulated walls of data while continuing to remain dedicated to upholding the larger public interest in the process.

Particularly in relation to *in situ* monitoring for long-term safety, both the concept of the safety case taken as the basis for long-term safety, and the technologic nature and specificities of the apt monitoring activities are highly expert driven and therefore almost inaccessible and incomprehensible to anyone who is not a highly specialised expert. The task of the regulator as go-between scrutinizing the activities of the implementer and translating in their own way the complex messages from monitoring data to understandable information on repository behaviour is not an easy one. The public has no real way of verifying either the implementer's or the regulator's interpretation of these highly sophisticated data and can only trust the safety authorities to do their jobs properly. As noted previously, a regulatory body is just as much a black-boxed expert system as the repository management system, and therefore demands that citizens place their trust in expert systems. However, as also pointed out above, perceptions of what Freudenburg (1993) called 'recreancy' or unintentional institutional failure can have a corrosive effect on trust in an agency to function competently and in the best interests of the ordinary citizen. It is telling, for example, that a recent review of past research studies that was carried out for the US Blue Ribbon Commission on Nuclear Waste found that neither the Nuclear Regulatory Commission, nor the

Department of Energy enjoyed a strong level of public trust, driven in great part by perceptions of past mistakes and failures (Tuler and Kasperson 2011).

A first element in assuring that there is potential for trust in the regulator is the overall framework of roles and responsibilities with regard to a countries radioactive waste management policy. Regardless of whether the role of implementer is given to the nuclear industry or to a state organisation, the regulator would have to be an independent body, with the means to perform its role appropriately (Weyman *et al* 2006; Bickerstaff *et al* 2008). Litmanen (2008) for example refers to the Finnish safety authorities financing their own 'independent' research to help them in their evaluation of Posiva's research and planning, and to help them prepare for their decision-making. Second this is about past experiences the public or particular actor groups have with the regulator; the extent to which regulators' track records suggest them to be trustworthy (see also Tuler and Kasperson 2011; NEA 2012c). A third element is the attitude of the regulator towards the public and specific stakeholder groups. In the past, regulators tended to steer away from getting involved with stakeholder engagement activity. The reason most heard for this, was wanting to avoid taking positions on issues (such as a safety case) too early in the process and thus risking to hamper the independence of a licence application review (Bergmans 2007; Kojo 2006). However, this position seems to be shifting, and the role of the regulator is evolving with the growing consideration for stakeholder engagement in the decision making on radioactive waste management. One such change in role, is that in several countries to date, regulators have become involved in public and stakeholder engagement activity, by providing independent expertise for local communities (NEA 2004b). The Finnish and Swedish regulators, for example, by positioning themselves as defenders of the public interest and 'allies' of the potential host communities, have gained the trust of the local communities involved in the siting process for the geological repository (Elam and Sundqvist 2006[57]; Varjoranta, Lucander in NEA 2002). A final element that could aid trust building is the introduction of organisational changes that open up the opaque 'black box' of regulatory and implementer systems of expertise, the basis of much of their decision making and therefore a critical element for citizens and stakeholders to understand. The accompanying increase in transparency could enhance public insight into how these systems work and of course enhance stakeholders' capacity to subject these decision making systems to more informed scrutiny; this may not always be a comfortable experience for the regulator but it could also work to reduce the sense that decisions are being made – or even that deals are being struck – behind closed doors which has been a perceived feature of regulation in many countries.

[57] The authors cite in this respect the municipal authorities of Oskarshamn: 'The government authorities are our experts: SKI and SSI participate throughout the siting process, our decisions are made after these authorities have expressed their views.' (www.oskarshamn.se/lko, 2005)

4.3.3 Monitoring the Monitor: Additional Mechanisms for Building Trust

Such 'opening up' could be organised through mechanisms that provide concerned actors, stakeholders and interest groups with the ability to intervene, to verify, contrast and contest claims made by the repository operator. By setting up arenas and mechanisms for traceability and control, greater transparency could be achieved, with implementers not stating: *"Trust us, we know what we are doing."*, but rather: *"Test us to decide if we are trustworthy."*[58].

Here we will focus on three mechanisms that we think could be of value to consider when putting in place an institutional framework for conducting monitoring:

- engaging independent oversight bodies;
- providing for local public arenas where monitoring results can be discussed and 'put to trial';
- give concerned actors the means and opportunity to call for second opinions or counter-expertise.

We see these mechanisms as being complementary to each other and as providing additional checks and balances, without in any way replacing the role of the regulatory agency or releasing it from its legal responsibilities. Together these different mechanisms may contribute to a more stable, traceable, transparent and trusted monitoring system[59]. Although such mechanisms could be put in place solely for the purpose of increasing confidence in technical monitoring activities, it would be both more coherent and very likely more effective if they were embedded within the overall approach to governance of the repository process (from pre-siting to post-closure).

4.3.3.1 Independent oversight bodies

One additional tool to enrich the institutional context for monitoring could be to make use of existing (or newly created) oversight bodies that are (or could become) recognised for their independence. Existing examples include: the French National Commission for Evaluation (CNE – *la commission national de l'évaluation*), the UK Committee on Radioactive Waste Management (CoRWM), the Swedish National Council for Nuclear Waste (Kärnafvallsrådet), or the US Nuclear Waste Technical Review Board (NWTRB). Such oversight bodies have a broader role in providing checks and balances

[58] This paraphrases an intervention during a plenary discussion at a conference on societal aspects of radioactive waste management (SKB Spring Talks, 3-4 May 2011, Stockholm), and echoes a phrase adopted by the US Chemical Manufacturers' Association in the late-1980s as a slogan for its Responsible Care programme: "don't trust us, track us" (see Simmons and Wynne 1993).

[59] 'Monitoring system' here refers to the overall socio-technical framework of monitoring arrangements (see also footnote 56).

concerning the management of radioactive waste in their country. In that regard they could take up an additional, explicit role in watching over a monitoring programme and scrutinizing implementers' analysis of monitoring results.

Such oversight bodies typically play a role at a national level. However, the most direct concerns regarding the safety of the repository may well come from local communities situated close to the repository site. This suggests that there may be a place for additional mechanisms at different levels to facilitate discussions on monitoring results, or more broadly on the safety of the repository today and in the future.

4.3.3.2 Public arenas at a local level to discuss safety issues and monitoring results

As with the oversight bodies, we do not envisage specific local arenas that are set in place for the sole purpose of debating monitoring results and the interpretation of data. Monitoring, as argued elsewhere in this report, is part of a bigger picture and should be treated within that context.

Within the logic of the stepwise decision-making model put forward by the NEA (2004a) and gradually implemented in many countries today, it seems likely arenas installed today to discuss (pre-)siting issues will continue or evolve to enable stakeholder engagement after siting, through licensing, construction and during operations. Such arenas, often situated at a local level, can provide a forum for discussing monitoring results. Examples of already existing arenas of this type would be: the Östhammar Community Groups in Sweden, the French CLIS, the UK Managing Radioactive Waste Safely (MRWS) partnerships or the Belgian local partnerships for the LILW repository in Dessel.

As discussed in Section 3 of this report, active engagement of a local community can be considered a valuable option for environmental monitoring. Such an approach seems far less realistic with regard to monitoring for long-term safety. However, this does not mean concerned communities could not in one way or other be engaged or participate in discussing the interpretation of monitoring results and what this means for the long-term safety of the repository. Having their own space to invite the implementer to make his case and the regulator to report on his safety analysis can provide a first step.

4.3.3.3 Enabling stakeholders to engage independent expertise

However, if we really want to enable concerned citizens and citizens' groups to 'audit' the actions of the implementer, they not only need a platform, but also access to independent expertise, to people and organisations they can call upon as their own 'scientific connoisseurs' (Evans and Plows 2007: 832). Such type of 'empowerment measures' (NEA 2002: 12) can be provided through centralised funding or on a contractual basis between an implementer or government and a specific community or stakeholder group. An example of the former is the Swedish Nuclear Waste Fund, from which concerned municipalities (since 1996) and environmental NGOs (as of 2004) can get financial support to participate in the EIA process connected with site investigations. With this funding, the community of Oskarshamn for example managed to mobilise external expertise previously employed by SKB and SKI, making radioactive waste management just as much 'their' business, as that of SKB and the regulator(s) (Elam and Sundqvist 2006: 45). An example of the latter is the funding provided by ONDRAF/NIRAS to the local partnerships for the LIWL repository project in Belgium, which among other things enabled them to command research on their behalf and invite experts of their choice to give their views on the issues at hand (Bergmans *et al* 2006: 70).

Both of these examples concern general funding schemes during a siting process, but similar initiatives could be envisaged during the stages of construction and operation (as was for example set as a condition for acceptance by the Belgian local partnerships). But as we saw in Section 3, concrete examples also exist of such empowerment mechanisms specifically related to monitoring activity such as the funding provided by the US DOE to the State of Nevada, 10 affected counties, and the Timbisha Shoshone Tribe to enable them to conduct independent scientific oversight on the Yucca Mountain project and to support the independent monitoring of the environmental impact of the WIPP (Bergmans 2010; NEA 2010a). Two of the French experts we interviewed referred to another, more ad hoc example of a situation in which the CLIS commissioned independent analyses of monitoring data collected by Andra in the Bure area. It was remarked that this may be more difficult with near-field monitoring, but that the possibility should not be excluded.

4.4 Monitoring as a Sign of Scientific Humility

The generally accepted view that repository programmes evolve in a stepwise manner has put more of an emphasis on the role of monitoring; particularly in view of a final decision to close the facility, which is generally considered a milestone decision involving regulatory and most likely political approval. Additionally, the progressive construction, operation and closure of the repository 'gives rise to the opportunity to associate a series of decision points to the disposal process from initial construction until closure' (MoDeRn 2011: 41). Such decisions are likely to be based, at least in part, on the output of a repository monitoring programme. Monitoring would therefore seem to have the potential of becoming a very important contributory element in determining the progress of the repository process.

If moving stepwise is the way forward for implementing geological disposal facilities, then this will have to be so over a considerably long period of time, thus having an impact on the aspirations and practices of monitoring itself. The MoDeRn *Contexts Report* indeed states that monitoring results are generally assumed to provide a significant basis for decisions on further disposal process management, including decisions to 'evolve, reduce or end monitoring activities' (MoDeRn 2011: 42). But even if the waste emplacement process is likely to last several decades, in many cases in the order of a century, some natural evolutions operate over time scales which are substantially longer, making them 'inaccessible to direct confirmatory monitoring' (MoDeRn 2011: 49). This directly touches the question of post-closure monitoring and the extent to which a societal need will remain for some continued monitoring at that stage.

This brings us back to the question of how much vigilance and for how long. As Weinberg pointed out, this is in essence a societal choice. But society and its decision makers cannot do this without making some commitment to trust in the repository system (or in the people implementing and inspecting it). Such commitment will be easier to make if during the progressive stages of conceptualisation, siting, licensing, construction and operation, there is the possibility to evaluate and to some extent reconsider this placing of trust. Monitoring (of different types, not restricted to in-situ monitoring) can help to demonstrate that the operator of the disposal programme acknowledges that there are remaining uncertainties and is willing to take precautions by being alert to unexpected evolutions of the repository system. In that respect, it would seem advisable to revisit the notion of stepwise decision making, with a stronger focus on possible steps between the start of construction and operations, and the aimed for closure of a facility. As far as governance questions, and public and stakeholder engagement in decision making in radioactive waste management go, the focus so far has mainly been on steps towards implementation (that is, siting and constructing) final disposal facilities. However, if we consider no disposal programme final before full closure of the facility (a position we can derive from most – if not all – of our sources pointing to the need to strive for passive safety), then more attention should be paid to the processes through which such a decision will or could be taken and how different actors could and should be engaged in that.

It appears that most radioactive waste and repository experts currently take the view that *in situ* repository monitoring will gradually decline and end with repository closure, not least because of the need to bar any form of instrumental intrusion that could compromise safety but also because of the limitations of contemporary monitoring technologies. To leave the decision to reduce and finally end monitoring to implementers and regulators would demand a huge commitment of trust from society;

whether that would be forthcoming would depend very much on the state of relations between those organisations and those affected by their decisions. It may be, however, that society is not willing to make such a commitment and to leave such decisions to operators and regulators. Better then to obviate this possibility and the negative effects on confidence and on practical relationships that would almost inevitably result from any emergent conflict by incorporating societal interests in decision making throughout the process. Similarly, given that scientists and technical experts are often accused of hubris and of a failure to recognise the risks attendant upon the limits of their knowledge[60], broadening the debate on monitoring objectives to consider not only the 'known unknowns', but also the possibility of 'unknown unknowns' occurring (see for example Böschen *et al* 2006; Stirling 2006), would show humility and recognition of the impossibility to foresee or plan for all contingencies.[61] It is important to acknowledge that the problems posed by different sources and types of uncertainty are not currently being ignored, indeed are being addressed in geological disposal research programmes.[62] Nevertheless, our point is that such possibilities need to be explicitly considered in the dialogue about developing monitoring objectives, and considered in a way that is open to societal input and responsive to societal expectations and concerns. This contains the risk of putting into question the premise of long-term passive safety as the geotechnical alternative to societal vigilance, or of delaying the move to final closure of a repository, but given convincing evidence during the staged process of geological disposal there is no reason to assume that this is inevitable.

Indeed, whereas monitoring could be seen as a sign of technological humility, one should also retain some humility about what monitoring can, and most notably cannot, deliver. A serious discussion of the limits to monitoring (including what could realistically be expected in terms of evolutions in monitoring techniques) should therefore be held early in the siting process, and not be restricted to the expert community, to allow for negotiation of objectives in the early stages of a programme so that societal expectations of monitoring information can be reconciled with feasibility constraints, without impairing the function that the repository system is intended to perform for society.

[60] See for example the discussions in Freudenburg (1988); Wynne (2001).

[61] The corollary of this, of course, is the need to acknowledge the fallibility of human institutions for the management of risk, however well designed they may be. This may result from an 'atrophy of vigilance' over time, especially in circumstances where nothing unexpected occurs for an extended period, or from some other form of institutional failure (Freudenburg 1992; 1993). Stakeholders are often acutely aware of this fallibility but, as we saw in Section 3, may reconcile mistrust of specific institutions with a desire for the maintenance of institutional control of a hazard by demanding more participatory forms of oversight or, as discussed in this section, a system of checks and balances that ensure independent monitoring of the monitors. A principle of humility and openness to the perspectives of non-experts has been advocated as a more general principle in relation to the deployment of expertise in policy (Jasanoff 2003).

[62] For example, in the European Commission's recent project on Performance Assessment Methodologies in Application (PAMINA), 2006-2009: http://www.ip-pamina.eu/index.html.

What is considered technically feasible may, of course, be rather different by the time that a particular repository programme begins the construction and operation phase. In any case, although we offer no prescriptions here, as the extent of any divergence between societal expectations and feasibility will not only be highly contextual, due to differences in national legislative and regulatory requirements and stakeholder demands, but resolution will be a matter for negotiation between implementer, national regulator and stakeholders.

The extent to which stakeholders view monitoring as a potential threat to the integrity of repositories, will depend on how they view the work of isolating radioactive waste from the biosphere as best progressing, and on the trust they are willing to put in the repository experts and their system. By introducing the notion of, respectively, retrievability or reversibility into law, Switzerland and France are already moving towards a more explicitly socio-technical solution to the social problem of radioactive waste: one that ultimately still relies on passive safety, but which puts this end point much further out than initially planned in order to accommodate societal caution about committing to this type of endeavour. Such evolutions confront us more directly with the fact that we will inevitably pass burdens on to next generations (e.g. the decision to close – or not – the facility). By acknowledging this, rather than by clinging to the unachievable goal of current generations settling the issue once and for all, it is possible to think more clearly about the information, knowledge and skills that need to be passed on to future generations in order for them to know and to exercise their options in light of future evolutions of a repository. Monitoring, it would seem, could play an important role by providing future operators, regulators, decision-makers and other concerned parties with valuable information. But again, one needs to remain modest about what information monitoring can deliver. Indeed, it has been pointed out to us that even if monitoring should give unexpected and apparently adverse results which suggest that 'something' is wrong, it need not necessarily mean that long-term safety is impaired. The question then is whether future generations will have the expertise to determine whether that is the case rather than simply intervening in some way, either to investigate or to retrieve the waste. The simple answer is that we cannot know but if there is an assumption among experts, which typically seems to be the case, that in the foreseeable future science and technology will continue to progress, the corollary must be that future generations capable of continuing to monitor will be as capable of interpreting any 'unexpected' results as current experts, and likely more capable if the knowledge and techniques available to them have advanced as expected. In the much longer timescale that raises questions about societal stability and cultural persistence ('cultural' here including the specific forms of knowledge that we know as science) it is hard to see how new forms of monitoring could be developed, to replace what would by then be the defunct monitoring systems established during repository construction and operation, and would be functioning without a corresponding set of institutional competences (both scientific and administrative). Nevertheless, we do consider that in view of decisions to be made by current generations, leaving options for monitoring to evolve and to respond to changes in the expected evolution of the repository (e.g. closure being postponed for one reason or other), it could reduce the requirement for unquestioning trust in those managing the radioactive waste by establishing for those who are ‘placing the bet’ means to exercise a form of control over the objects of their trust, as well as providing the reassurance of a potential back-up arrangement.

5 General Conclusions

In this report we have explored expert views on repository monitoring as well as reviewing what the social science research literature tells us about the expectations and motivations that are likely to influence lay stakeholders' attitudes towards monitoring. The exploratory stakeholder engagement exercises planned in the next phase of this research will build upon this review and are intended to supplement the inferences, reported above, that we have drawn from the research literature. In this final section of the report we shall therefore consider the implications of our findings so far for engaging different types of stakeholders, in particular lay stakeholders, in defining monitoring objectives and strategies.

One thing the expert community definitely agrees upon is that issues of (re)assurance and confidence building are among the main drivers for monitoring. The vital question then becomes how to organise monitoring in such a way that it answers different stakeholders' expectations, thus contributing to raising their confidence in a repository performing to the promised standards of safety.

A first general observation to make is that monitoring is part of a bigger story. Monitoring is not an end in itself; rather it is a means to support, in a number of ways, the implementation of geological disposal. This suggests that policy and implementation bodies should not focus too much on separate engagement activity on monitoring, or dwell on specific engagement techniques. Setting aside exploratory research such as that to be conducted as part of MoDeRn, one implication of this would be that any engagement with stakeholders on monitoring should be set up as part of a wider consultation and participation process dedicated to the question of geological disposal. Given the potential mediating role that it may play in relation to stakeholder confidence, however, it seems on the other hand advisable for existing and emerging stakeholder engagement programmes to dedicate due attention to the issue of monitoring. This can be considered to apply both at a national level, in relation to general policy questions of whether or not to opt for geological disposal and to more specific questions of reversibility and retrievability, and at the local level, in relation to implementation of national decisions.

A second observation deriving from our research so far is that the way in which people view monitoring and what they expect to obtain from it differs according to (among other things) the way they view the concept of geological disposal and long-term safety. So, on the one hand, some have great confidence in the multi-barrier design providing multiple safety functions to ensure long-term safety, seeing monitoring primarily as a means of confirming the models on which they have based the repository design and which are used to make the case for long term safety after closure, but as having no active safety role in the post-closure phase. Others acknowledge that there may still be unresolved uncertainties and that it would likely be necessary to maintain some form of monitoring (not necessarily *in situ*) into the post-closure period if society required continued assurances that there were no unexpected evolutions of the repository system. This is not simply a matter of a difference between 'expert' and 'lay' perceptions. As the different sections in this report have shown, there is more than one way of interpreting passive safety as an alternative to active and virtually perpetual vigilance. Background assumptions are often, by their very nature, not made explicit and for those holding them may assume, in the course of everyday reinforcement by a like-minded community of practice, the unreflective status of common sense. When engaging with different types of stakeholders, therefore, those responsible for developing and implementing repository monitoring strategies as part of national HLW repository programmes will not only need to take into account the existence of different conceptualisations but also to focus their interactions with stakeholders on making explicit what lies behind different actors' views on monitoring, including their own.

Third, and related to this, is that we found monitoring could be part of the answer to the societal expectation that vigilance should be maintained at all times. Whether we like it or not, burdens will inevitably be passed on to future generations. First, because in most programmes it seems unlikely that geological repositories will be closed by the same generation who build them. Second, because certainty and safety can never be guaranteed. By broadening the debate on monitoring objectives to consider how to register things previously unthought-of and thus considering not only the 'known unknowns', but also by considering the problem of 'unknown unknowns', experts, so often accused of hubris, can show humility and recognition of the impossibility to foresee and plan for all contingencies. This also means showing preparedness to discuss monitoring issues not only in view of preparing for closure (the main purpose for monitoring from a technical expert perspective), but also with regard to a post-closure phase, or in view of a preliminary abandonment of the site, or final closure being indeterminately postponed for one reason or other.

However, this does not mean such issues need to be settled here and now for the full length of the disposal process. What seems important is that monitoring programmes are designed so that they remain flexible enough to cater to changing social and regulatory expectations placed among them. To continue building confidence, both the product and process of monitoring will have to continue meeting different stakeholders' expectations, while staying within the limits of what is scientifically sound and both technically and financially feasible. When developing and maintaining monitoring programmes, a two-way interaction with different types of stakeholders is needed, in order to get these elements integrated and in balance. The weighing of these elements against each other is something that concerns society as a whole, and not something an implementer should do on its own; nor should it be left solely to technical regulatory decisions.

This brings us to our fourth observation that in order to develop and sustain societal confidence the process of monitoring should be transparent and open to public and expert scrutiny. As was argued in this report, this is not done by merely producing data and arguing how these corroborate experts' claims and models. What is as important (if not more) is to produce these data in such a way that others have access to them and are able to verify how they came about. Again, this is not an issue of monitoring alone, but will have to be incorporated into the institutional context by which roles and responsibilities for long-term radioactive waste management are organised. Important components of such a context include:

- A framework that establishes the role of monitoring as a tool for increasing transparency.
- An independent regulator which has the means to perform its role appropriately, has an excellent track record, and is itself open and transparent towards the public.
- An independent oversight body at the central level, the form of which may differ in different countries (e.g. a national review board, or a national oversight committee) but which would be distinct from the regulator.
- Measures to empower concerned stakeholders at the local level in relation to monitoring activity, either by engaging external experts of their choosing or through active involvement in the monitoring process (for example in environmental monitoring).

The extent to which the additional measures for 'monitoring the monitors' outlined in the last two bullets are necessary for confidence building will depend very much on the (national) context but they reflect solutions described in this report as well as reflecting insights offered by research on trust and confidence in the context of technological risk.

Finally, we conclude that a more fully social (rather than merely psychological) conception of trust, as elaborated above, is central to understanding the extent to which monitoring may contribute to building confidence in geological disposal. Monitoring programmes may well be able to contribute to public and stakeholder confidence in long-term radioactive waste management, and specifically geological disposal; this requires however not only that we *recognize* repository monitoring as a socio-technical activity requiring social and institutional innovations as much as technical innovation, but that this is *acted* upon.

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7 Appendix: list of people interviewed

Interviewees are listed here in alphabetical order. Apart from those indicated as soc (social scientists) and com (communication experts), all hold a technical function.

Luis Aparicio (soc) - Andra
Philip Birkhauser (com) - Nagra
Enrique Biurrun - DBETEC
Brendan Breen - NDA
Stéphane Busschaert - Andra
Christophe Depaus - ONDRAF/NIRAS
Sébastien Farin (com) - Andra
Bernd Frieg - Nagra
José Luis García-Siñeriz - Aitemin
Michael Jobman - DBETEC
Lawrence Johnson - Nagra
Louis Londe - Andra
Juan-Carlos Major - Enresa
Stefan Mayer - Andra
Nina Müller-Hoeppe - DBETEC
Maarten Van Geet - ONDRAF/NIRAS
Hughes Van Humbeeck - ONDRAF/NIRAS
William Wacquier - ONDRAF/NIRAS