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Technical Monitoring and Long-Term Governance of Nuclear Waste

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Band 21

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Inhalt

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Technical monitoring and long-term governance – an introduction

1 Overview

If high-level nuclear waste is disposed in a deep geological repository with the option of retrievability, it is necessary to monitor the development of the waste underground. Without the information gathered during monitoring, it would be impossible to know whether the state of the waste and the repository is as planned or whether an unwanted development has occurred. If the data collected deviates from the expected development, complex social processes have to take place in which the significance of the deviation is negotiated. Possible reasons for the deviation must be discussed and evaluated in terms of their plausibility. Based on the results of this discussion, a decision must be made on the kind of measures to be taken – of which retrieval would be the most extreme. If it has been decided that retrieval is necessary to ensure the safety and security of the site, information on the state of the repository is needed to safely plan retrieval activities.

Monitoring in this context means the temporary technical collection of data on the development of the repository and its social and technical surroundings in combination with the social processes of data interpretation (based on Hocke et al. 2012). To enable decision making, it must be decided which parameters need to be monitored and how this should be realized technically. There is no experience yet with the durability of monitoring techniques and technologies over a period of several decades to centuries. Any monitoring equipment installed underground cannot be repaired or exchanged once the repository has been closed. The precautionary principle demands that the possible occurrence of a situation in which retrieval is considered necessary be taken seriously. This means that precautionary actions must be taken now. This includes, for example, the incorporation of monitoring into the repository design, research on monitoring technologies, as well as debates about contextual factors for retrieval. So far, the debate has been limited and critically received in parts of the technical and scientific disposal community.

Further, taking into consideration current decision-making structures and calls for public participation, it can be assumed that the site operator will not be able to perform the interpretation of the data alone. Safety authorities, supervisory bodies, as well as scientific actors and stakeholders will have considerable interest in participating in such a task. In addition to the technical issue, an institutional setting must be found in which such a variety of actors can cooperate and make responsible and informed decisions.

2 Background

German high-level nuclear waste mainly consists of spent fuel rods from nuclear power plants and vitrified waste. When the first power plants were built in the mid-20th century, the waste was not considered a major problem. Rather, visions of a closed fuel cycle in which the waste would be reprocessed and reused dominated the debate. The fact that these reprocessing technologies also produce nuclear waste that requires an underground repository was not of particular interest. Since then, rather than being considered a minor problem, waste has come to dominate much of the debate on nuclear issues and has become a major subject of regulation. In several countries, entire public institutions are devoted to identifying a suitable repository site. This change can be interpreted as being due to reflexive modernization in which constant reinterpretations from resource to waste and vice versa take place and in which society attaches meaning to these wastes and the associated problems through processes of reflection (Kuppler 2017, based on Beck 1996 and Keller 2000).

As a result of these processes, attempts at solving the problem of "high-level waste disposal" have been strongly influenced by the debates on the use of nuclear power for energy production as well as by the political conflicts that have shaped this field in many countries ever since the first nuclear power plant was built. At the same time, this problem requires the attention of generations of researchers, policy makers, industry representatives, and citizens alike. The time span over which a repository is supposed to keep the waste safe and secure in Germany is one million years. This is of course not the time span over which some kind of human control is expected or deemed necessary. Still, also the time spans during which active or passive control must be realized are very long compared to planning periods for other industrial facilities. Visions of a quick succession of planning, construction, and closure of a so-called "maintenance-free" repository have proven unrealistic (Hocke et al. 2012).

The German Site Selection Act that came into effect in 2013 states that retrievability should be possible during the operation phase, i.e., during the period when the waste is brought underground. Further, the waste should be retrievable for 500 years after closure using mining techniques. In the meantime, more detailed requirements regarding the safety of a repository have been issued in Germany.[1] Despite careful planning, it can never be known whether a repository is really safe (cf. Berkhout 1991). In order to be able to retrieve the waste, the final storage containers in which the waste is stored would need to remain intact over this period. In order to retrieve the waste, information on the state of the underground repository and its surroundings is required. This information is usually gathered by technical monitoring. For an underground repository, monitoring techniques must be used that require no maintenance after closure of the repository. Such techniques are not readily available.

So far, few attempts have been made at defining the kinds of tasks that will need to be carried out in and at a repository over periods of 500 years or more and who will be responsible for performing and coordinating them. An example of such an attempt is the long-term stewardship program developed by the United States Department of Energy (e.g., U.S. Department of Energy 1999). This defines tasks that need to be accomplished over the next 100 years. Czada (2016) argues that long-term planning is a question of institutional settings. The scientific debate on who should decide in the future and what kind of information and competences future decision makers need in order to be able to act has just started (Kuppler/Hocke 2018). This anthology takes up the debate and intends to contribute from the perspective of various disciplines by approaching questions such as what the technical requirements for monitoring activities are, how legal studies interpret the institutional aspects, or what role public participation could play in long-term governance.

3 On the challenge of planning over long periods of time

3.1 Unbounded technologies

Technologies often have both intended and unintended effects that are unbounded in their spatial and temporal potency. Current political systems often struggle to find appropriate answers to problems associated with unintended effects. With regard to the hole in the ozone layer, coordinated action by many nations has been successfully implemented. Combating climate change, on the other hand, requires such profound changes in our economic activities that coordinated action is much more difficult to achieve. It also requires changes that take at least several decades to implement, such as transforming the energy

1 The Repository Safety Requirements Ordinance (Endlagersicherheitsanforderungsverordnung – EndlSiAnfV) came into force in October 2020. It specifies that retrieval should be possible without major effort until the start of closure of the repository (§ 13). Retrieval should be possible for 500 years after closure (§ 14).

system from one based on fossil fuels to one based on renewable energy. For example, a study published by the German Environment Agency (Umweltbundesamt – UBA) has suggested that the transformation of the German energy system from fossil-based to renewable energy should be completed by 2050 in order to reach the emission reductions aimed for (Klaus et al. 2010). Changes in government coalitions and indecisiveness in implementation can lead to several changes in the plan, which may to some extent question the original goal set. There seems to be a contradiction between the political focus on election periods and the need for long-term planning (Czada 2016). On the other hand, Gärditz (2013) argues that long-term planning is undemocratic since any democratic decision must be reversible. He argues that long-term planning involves balancing very different values: On the one hand, long-term interests that relate to the abstract bad that could happen in the future due to climate change; on the other hand, immediate threats such as, e.g., to biodiversity from the construction of renewable energy facilities. In his opinion, public institutions are not equipped to make such decisions.

Full reversibility is hardly ever a given with regard to technological infrastructures. Once the decision has been made to decommission a power plant and dismantling has started, it cannot simply be reversed. Calling for reversible decisions would imply maintaining the status quo. What reversibility can mean in the context of technological system changes and long-term tasks such as nuclear waste management is allowing for alternatives in a long-term plan and determining what resources and skills need to be developed so that institutions will be able to handle the technology and the associated societal impacts also in the future.

In order to be able to regulate the impact of technologies on society and the environment, information about their state is gathered with the help of technical monitoring. Mostly, environmental monitoring is about controlling the success of cleaner technologies on the one hand and controlling adherence to environmental regulations on the other. In many industrialized countries, it is standard procedure to equip industrial installations potentially emitting pollutants into the air or water with some kind of monitoring. Yet, for a planned nuclear waste repository, the debate on what kind of technical monitoring is needed and possible has only just begun. Monitoring in this context is discussed as one approach to dealing with the temporal unboundedness of the problem. Particularly technical experts often understand monitoring in this context as a technical tool to take care of all challenges and risks related to the underground infrastructure. In Germany and other countries planning for an underground repository, the preferred type was a maintenance-free underground repository[2] for a long time. For such a facility, technical monitoring would only be possible above ground, e.g. of air and water quality. In several countries, the debate has moved on and nowadays a type of repository with retrievability is planned for.[3]

To realize such a technical monitoring, two prerequisites need to be fulfilled: first, it must be decided which parameters are to be monitored and, second, technical solutions must be developed to actually monitor these parameters. Both prerequisites are not easy to fulfil. The parameters selected should provide the information needed to be able to judge whether everything develops as planned and, if it is not going as planned, whether this has implications for the safety of the repository that, in the worst case, would require retrieval of the waste. In what cases retrieval would be necessary is by no means clear. Thus, it is also not clear what would be suitable termination criteria. Existing monitoring techniques have never been used over such long periods of time without the possibility of maintenance, including replacement of parts. Developing such monitoring techniques that can reliably provide secure data over a very long time span without maintenance is a considerable engineering challenge.

An additional challenge is that some kind of long-term institution is needed that can interpret the data delivered by the monitoring technology and make decisions based on it. Interpreting the data and acting upon it means that the institutions must be able to decide whether a deviation from standard values implies a measurement error, an acceptable deviation, or whether measures need to be taken, such as retrieval of the waste. If action is considered necessary, the long-term institution needs to be able to activate other political and administrative institutions and civil society in its surroundings. Those institutions do not need to have detailed knowledge and skills to interpret monitoring data but need to cooperate in implementing measures deemed necessary by the long-term institution. To do so, the long-term institution must be able to muster resources even when public and political interest wanes. In addition to its technical abilities, the long-term institution must be able to keep up a dialogue with the public, in particular the local public (Kuppler/Hocke 2018). To fulfill these tasks, "learning institutions" are needed.[4] The currently responsible institutions

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2 The term "maintenance-free" repository stands for the idea that with closure of the repository passive safety will be achieved, which eliminates the need for human control (e.g., Hocke et al. 2012; Kirch et al. 1990).

3 An underground repository with retrievability is constructed such that the waste can be retrieved with reasonable efforts if deemed necessary (e.g., Kommission Lagerung hoch radioaktiver Abfallstoffe 2016).

4 In Germany, the Repository Site Selection Act (Standortauswahlgesetz – StandAG) prescribes a "learning procedure" for the institutions involved. The StandAG itself has already proven to be

in Germany do not seem prepared to undertake such tasks and to cooperate in the necessary way. This shows particularly in the case of the Asse mine (see Hocke et al. 2016). What steps institutions must take to be prepared to take responsible decisions and actions in the future is an open question.

3.2 Current approaches

Currently, only one management concept dealing with long-term issues can be identified in the literature on nuclear waste management: The term "long-term stewardship" stands for a program developed by the U.S. Department of Energy (DOE) with the aim of coordinating the long-term management of nuclear sites, both military and others (U.S. Department of Energy 1999). It mainly lists tasks that need to be fulfilled if institutional control is to remain active. It is assumed that such institutional control can be provided for 100 years from now (U.S. Government Printing Office 2006). Experiences with the concept point to an important lesson: it is very difficult to foresee the economic costs of performing necessary tasks over a longer period of time and thus to allocate resources accordingly. At the same time, the concept does not address the important aspect of institutional requirements necessary to ensure that the tasks identified can actually be carried out (Kuppler/Hocke 2018).

This was also a topic of a keynote Metlay presented at an ITAS workshop in 2016, upon which this compendium is based (see section 4 in this introduction). Metlay pointed out that it is often assumed that such tasks are "self-implementing," i.e., that implementation is an inherent part of task identification (Metlay 2016). He argued that such an assumption is particularly problematic when it comes to monitoring as organizational issues play a major role, such as how to evaluate the information obtained from monitoring and how to decide whether to change plans when there is no agreement that a change is necessary. In his view, this would lead to two possibly contradictory characteristics that a monitoring organization would have to fulfill: it would need to be independent to be able to provide reliable and valid data and at the same time interdependent to organize discussion about the meaning of the data. Some kind of hybrid institution would be needed (Kuppler/Hocke 2018). Regarding the technical aspects, the key question in his view is: What should be measured and how can reliable measurements be taken?

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a "learning system," as it has been adapted several times after consultations with experts and the public (Smeddinck 2017; see also Mbah/Brohmann 2021).

The questions raised in the opening talk can be understood as guiding questions for the whole workshop and this anthology.[5] First, the organizational question of the embeddedness of a monitoring institution and, second, the technical question of what and how. Czada (2016) also argues that long-term planning is a question of coordination and interaction, and thus of institutional settings. It can therefore be understood as a governance problem in which coordination and cooperation need to be organized (cf. Grande 2012; Mayntz 2009). In this anthology, Mbah adds to this debate by looking at public participation and Smeddinck et al. by looking at legal questions of long-term institutions.

The technical debate on the what and how has so far mainly been addressed in two projects funded by the European Union: MODERN and MODERN2020 (see the final conference report MODERN2020 2019). In their contribution to this anthology, Jobmann and Liebenstund present some results from the latter, with a particular focus on the interplay between the technical and the social. Still, from a technical point of view, many questions remain open, not least because appropriate monitoring also depends on the disposal concepts favored, which differ considerably between countries.

The solution to the technical problem is highly complex as the safety requirements for a monitoring approach do not necessarily coincide with the safety requirements for the repository structure. Thus, it is essential that a broad range of technical disciplines engage in an intensive discourse on the effects of the boundary conditions defined by each discipline on the feasibility of different monitoring approaches. On the one hand, this discussion should provide an overview of what is technically feasible and, on the other hand, the basis for what is socially feasible. However, there are no comprehensive overall approaches, neither technical nor social, to overcome the challenges associated with monitoring a repository underground. One example of such a challenge is the wireless transmission of measurement data through the repository rock, which is technically unresolved but a necessary prerequisite for achieving hermetic containment of the waste materials.

The identified need for institutions capable of collecting meaningful and reliable data and organizing a debate on the meaning of this data points to the need for interdisciplinary research. This type of research could help not only to understand the technical difficulties or the problems of institution building but also to analyze and advance knowledge about the socio-technical interplay in

5 Some of the contributions in this anthology are based on presentations made at the workshop. Others were added subsequently to broaden the perspectives on monitoring and long-term governance.

which such long-term governance settings develop.[6] This is of particular importance because the questions of what should be monitored and how monitoring should be organized cannot be answered by researchers alone (Bergmans et al. 2012).

4 From the idea to the anthology

This book is mainly based on research conducted within the ENTRIA project ("Disposal options for radioactive residues: Interdisciplinary analyses and development of evaluation principles").[7] In ENTRIA, interdisciplinary research was carried out on several topics related to nuclear waste management and mainly organized bottom up. This means that the research topics were developed in discussions during the project. The aim of most interdisciplinary research endeavors in ENTRIA was to investigate a particular problem by including different problem perspectives, rather than to develop interdisciplinary research methods (e.g., Brunnengräber et al. 2016; Röhlig et al. 2017; Köhnke et al. 2017).

Not long after the launch of ENTRIA, it became clear that a new political attempt would be undertaken to end the stalemate in decision-making on nuclear waste management in Germany. The StandAG was drafted and enacted, and the Commission on the Storage of High-Level Radioactive Materials was established. In its final recommendations, the Commission advocated for an underground repository with retrievability, without further elaborating on the details of what retrievability could mean in practice (Kommission Lagerung hoch radioaktiver Abfallstoffe 2016). Switzerland is one example of a country that has planned for retrievability. Since research in this field is still in its infancy, the ENTRIA members interested in this topic had to decide how to approach such a complex issue. An interdisciplinary and international workshop on "Technical Monitoring and Long-Term Governance" was considered a suitable approach. Such a workshop can provide a first insight into the state of the art and the potential contribution different disciplines can make to the academic discussion of this problem. It can help further debate on different aspects of the problem and provide a basis for discussion of new conceptual ideas.

6 An overview of approaches to socio-technical problems can be found, e.g., in Lösch 2012. For a debate on interdisciplinary research in nuclear waste management, see Smeddinck et al. 2016.

7 ENTRIA was a joint research project funded by the German Federal Ministry of Education and Research (BMBF, support code: 15S9082A) that ran from 2012 to 2017. For the program of the workshop and slides presented, see https://www.itas.kit.edu/veranstaltungen_2016_entria_temo.php [Accessed 14.01.2022].

The workshop was therefore attended by representatives from a variety of disciplines, including legal studies, science and technology studies (STS), geophysics/geology, radiochemistry, political science, institutional psychology, and engineering. They contributed ideas on technical possibilities for monitoring as well as research needs, perspectives on requirements for learning institutions, the role of uncertainty and ignorance, and experiences from the United States and Switzerland. Participants included: Dr. Anne Eckhardt (risicare), Prof. Dr. habil. Oliver Sträter (Kassel University), PD Dr. Stefan Böschen (ITAS at KIT), Dr. Anne Bergmans (University of Antwerp), Dr. Daniel Metlay (Member of the Senior Professional Staff of the U.S. Nuclear Waste Technical Review Board – NWTRB), Prof. Dr. Armin Grunwald (ITAS at KIT, former member of the German Commission on the Storage of High-Level Radioactive Materials, current member of the German National Citizens' Oversight Committee [Nationales Begleitgremium]), Prof. Dr. Horst Geckeis (INE at KIT).

All participants were invited to contribute to the present anthology, either in German or English. Furthermore, selected authors who could not attend the workshop were invited to contribute. A majority of the contributions were discussed at a meeting between the authors and editors. Each contribution was assigned to a participant who read the respective manuscript carefully and served as discussant during the meeting. This ensured that the contributions were written in a way that is comprehensible for an interdisciplinary audience. After the meeting, the contributions were revised and submitted to a final review by the editors. Contributions that could not be discussed at the meeting were subjected to an internal review. Thus, ideas from the workshop were scrutinized and further developed before being published in this compendium.

5 Overview of the contributions

The successful implementation of radioactive waste disposal depends on technical aspects, such as a sound strategy for ensuring safety and security, as well as scientific and engineering competences. Social aspects such as acceptance and trust of the different interest groups are another prerequisite. Monitoring is considered key to fulfilling all of these aspects. In their contribution, Jobman and Liebenstund discuss results of the MODERN2020 research project. Based on the guidelines developed within the MODERN project, MODERN2020 aims to provide the basis for the development and implementation of an efficient monitoring system for a final repository. The aim is to understand what should be monitored as part of the safety case and to provide a method for using monitoring results to support decision-making processes. Furthermore, MODERN2020 specifically aims to effectively involve local interest groups (stakeholders) in R&D monitoring activities. In this context, the general question of how successful cooperation can be organized and at what point of time in the process the involvement of local interest groups is meaningful and effective is to be clarified in dialogue with stakeholders.

Anne Eckhardt shows in her contribution that Switzerland follows a very specific concept of deep geological disposal for the management of radioactive wastes. This concept combines society's need for controllability with the strengths of classic approaches to radioactive waste disposal. At the disposal site, a pilot repository will be installed in the vicinity of the main repository where the majority of waste will be stored. The pilot repository must be representative of the main repository, but at the same time spatially and hydraulically separated. After closure of the main repository, provisions will be made for long-term monitoring in the pilot repository. In general, and particularly with regard to the pilot repository, the monitoring configuration in a geological repository requires not only technical and scientific knowledge but also supervision by members of civil society and the social sciences and humanities. From an ethical point of view, it is not possible to weigh the pros and cons of monitoring with regard to safety. Thus, a political decision must be made whether the decrease in uncertainty through monitoring outweighs the additional calculable risks associated with it.

Karl-Heinz Lux et al. argue that the intended monitoring concept for the planned repository needs to be discussed already now during the site selection process. The reason is that the monitoring concept can influence the selection criteria, e.g., due to the required space. They describe the basic idea behind the monitoring concept developed in the course of the ENTRIA project, which provides for a second level above the repository, from which monitoring boreholes reach the emplaced waste. They argue that with this setup, monitoring can take place during and after emplacement, thus contributing to intergenerational equity. Lux et al. also present some first results from their thermal, geomechanical, and fluid dynamic modeling of the development of such a two-level repository.

Any decision on the potential retrieval of high-level radioactive waste from the repository requires a sound data base. This data must be collected in a monitoring program that must be applied during the entire operational phase of the repository. It is yet unclear how monitoring will be integrated into the repository design. Volker Mintzlaff et al. discuss a generic repository design to meet this requirement. The approach presented considers a two-level mine in which monitoring is possible via boreholes drilled from the upper level to the closed emplacement drifts in the lower level. Due to the long operational phase, the monitoring devices must be replaceable. They further discuss the setup of the monitoring program in different host rocks and the trade-offs between the