Information and knowledge preservation over generations in a regulatory context

Abstract

This text discuss the regulatory framework for the preservation of records, knowledge and memory regarding repositories for radioactive waste. A discussion that is equally applicable for other disposal sites containing, for example, non-radioactive, long-lived hazardous wastes or potential injection sites for carbon dioxide storage. The text intends to give a background to the questions raised in Theme 2: Law and Regulation and long-term responsibilities on preservation of memory in society. The viewpoints expressed in the text are those of the author and do not necessarily coincide with those of the Swedish Radiation Safety Authority.

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Introduction

Safety assessments for geological repositories for radioactive waste cover a broad range of scientific areas and large amounts of information; they typically involve numerical modelling simulations in order to make evaluations of the long-term evolution of the repository system after closure. Such analyses will tend to address several alternative scenarios, chosen to address the safety significance of possible evolutions. Some analyses explore the consequences of certain scenarios regardless of their likelihood of occurrence. The post-closure evolution of a passive repository system is predicated on natural laws rather than societal aspects. Thus, uncertainty of outcome is mainly related to lack of knowledge, i.e. *epistemic* uncertainty relating to the disposal system that can, at least in principle, be reduced through more research, method development etc., or addressed through sensitivity studies and/or conservative assessments.

Inadvertent human intrusion into a repository for radioactive waste presents a different and important epistemic problem since it is dependent on phenomena related to societal aspects. Accordingly, the siting process and design of the facility include aspects that seek to reduce the probability, and consequences, of inadvertent future human impact on the repository [1], [2]. From a technical, environmental and ethical point of view, geological disposal relying on passive safety controls is the internationally advocated alternative [3]. "*Nevertheless it is ethically incumbent on current generations to make a good faith practical and practicable effort to inform the future of risks that have been placed underground*" [4].

A better-known area where large efforts are being made to perform long-term predictions regards the future climate. The climate-related impact on human society is an important aspect of current future studies, which aim to explore how human behaviour needs to be changed in the present and near future in order to avoid a less preferable distant future. The future risk and impact of a human-induced changing climate are problems that future generations will have to live with, whereas past and present generations are the beneficiaries of activities that give rise to such consequences. The ethical dimensions regarding responsibilities towards the future are shared among the generations that use nuclear energy, in the sense that the produced waste will be hazardous for very long times.

A recent NEA project examined how records, knowledge and memory (RK&M) of a geological repository for radioactive waste can survive over the generations to come after the facility is closed and sealed [5]. One key conclusion from the RK&M project is that the waste-producing generation are

obliged to support informed decision making by future societies. Providing such information will also contribute to reducing the possibility of inadvertent intrusion. The RK&M project also concludes that there is no single key to unlock the challenge of meeting this obligation. Rather there are many different keys; different paths created by the present generation, paths that strengthen each other and increase the possibility that records, knowledge and memory of a nuclear waste repository will be preserved over the generations. One of these paths is the regulatory framework.

> *The future is not a result of choices among alternative paths offered by the present, but a place that is created —created first in the mind and will, created next in activity. The future is not some place we are going to, but one we are creating. The paths are not to be found, but made, and the activity of making them changes both the maker and the destination* [6].

The Swedish national regulatory framework with regard to RK&M and radioactive waste management

Internationally-agreed principles for long-term management of radioactive waste are to isolate and contain such materials, in order to prevent or control the release and dispersion of radioactive substances. The aim is to ensure that the hazard is kept away from contact with the biosphere for as long as possible. A consequence of isolating and concentrating the waste, rather than diluting and dispersing it, is that inadvertent disturbance may occur as a result of future human actions, which in turn may result in exposures to radioactive materials and/or their release to the environment [1]. This means that the acceptance of a repository for radioactive waste, or indeed any other long-term storage arrangement, also involves the acceptance of a certain risk of potentially high doses in connection with future inadvertent human intrusion. Such risks can however be reduced through repository design, site selection and RK&M preservation.

Information and knowledge preservation

Repository records

In the governmental ordinance specifying general instructions for SSM (SFS 2008:452) it is stated that the Authority shall contribute towards the development of national competence for the needs of today and tomorrow within the Authority's area of operation. This includes activities concerning the disposal of nuclear material and nuclear waste.

The regulatory framework in Sweden supporting RK&M preservation is composed of regulations formulated by the Swedish Radiation Safety Authority (SSM) and the National Archive (see appendix). SSM's regulations are mainly concerned with the handling and preservation of records for as long as a licensed nuclear activity is conducted at the facility. A general advice on the application of the regulation SSMFS 2008:37, relating to the final management of spent nuclear fuel and nuclear waste [2], states that:

> […] *consideration should also be given to the possibility to reduce the probability and consequences of inadvertent future human impact on the repository, for instance inadvertent intrusion. Increased repository depth and avoidance of sites with extractable mineral assets may, for instance, be considered to reduce the probability of unintentional human intrusion. Preservation of knowledge about the repository could reduce the risk of future human impact. A strategy for preservation of information should be produced so that measures can be undertaken before closure of the repository. Examples of information that should be taken into consideration include information about the location of the repository, its content of radioactive substances and its design.*

This is consistent with the first paragraph in Article 17[1] of the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [7].

SSM has also issued regulations and guidelines regarding requirements for proper filing, archiving and long-term preservation of records from licensed nuclear facilities (SSMFS 2008:38). This regulation gives general guidelines regarding document selection and for how long certain documents should be saved in the archives (SSMFS 2008:38, appendix 1). Furthermore, SSMFS 2008:38 refers to regulations published in the statutes of the Swedish National Archives (Riksarkivet, RA). RA's regulations mainly concern the proper handling of documents, on paper and electronic media, as well as the construction and maintenance of archives for ensuring the longevity of records.

Hence, there are some existing relevant guidelines and regulations in Sweden relating to *what* kind of information should be passed on to future generations, i.e. the location, content and design of a repository, and *where* this information should be preserved, i.e. archived. This kind of information is consistent with one of the NEA's RK&M project deliverables, the so-called *key information file* (KIF), which provides a very condensed record of a repository and the activities that occurred at the facility, addressed to a non-expert audience. The intention is that such information should support preservation of the memory of the repository and the hazard it represents and thereby reduce the possibility that inadvertent intrusion might occur. There are other repository records that have other purposes, i.e. not only dedicated to preserving the memory of the repository's existence. An example of this is the *set of essential records* (SER), another deliverable from the RK&M project, the intent of which is to provide future generations with the tools and information needed to undertake their own safety assessment or, depending on decisions made at that time, to safely retrieve deposited material. Such information is therefore addressed to a technical audience.

Thus the present national framework in Sweden answers, to some extent, the questions:

- *what* kind of information should be preserved, i.e. location, content and repository design
- *where* it should be preserved, i.e. according to national archiving arrangements
- *why* it should be preserved, i.e. memory keeping

Since the implementing organisation responsible for geological disposal has produced the underlying information, they should also be responsible for creating the repository records, for instance KIF and SER. If specific regulatory requirements are developed in this area, the responsible authority will need to review the information for compliance with regulatory requirements. Examples of questions that might be relevant to the development of regulatory requirements include:

- At what intervals do the repository records need to be revised and updated in order to keep the information readable and understandable?
- To what extent should other stakeholders be part of the reviewing process during the process of revising and updating records?
- How should the handover of responsibilities practically be implemented, for example with regard to the regulating body's involvement in revising and updating repository records at the time of closure?
- Which are good practices to keep in mind?

[1] Article 17. Institutional measures after closure
Each Contracting Party shall take the appropriate steps to ensure that after closure of a disposal facility:
(1) records of the location, design and inventory of that facility required by the regulatory body are preserved;
(2) active or passive institutional controls such as monitoring or access restrictions are carried out, if required;
(3) if, during any period of active institutional control, an unplanned release of radioactive materials into the environment is detected, intervention measures are implemented, if necessary.

- The SER document is very substantial compared with the KIF document. The final SER needs to be completed, at latest, at the time of closure. Should the final SER documentation follow a step-wise development process similar to that for the facility's safety analysis (e.g. pre-construction, trial operation, routine operation)?

Knowledge management

Records are only useful if the reader can understand their meaning, and it has been argued that the focus therefore needs to be on the preservation of knowledge and how records can support this [8]. Furthermore, the preservation of knowledge for future generations depends largely on a continued, successive transfer across generations. On a timescale of centuries or much longer, however, societal and technological discontinuities can occur where knowledge is lost. Consequently, a knowledge retention strategy, or action plan, needs to be developed and implemented. For example, knowledge at risk of being forgotten could be preserved by using a "mothballing"[2] strategy [8]. Today, it needs to be explored how the regulatory framework can support strategies for knowledge preservation and its retention when lost. Which are the best practices regarding knowledge management? Also, who should be responsible for the development and implementation of such a strategy considering the transfer of responsibilities after repository closure?

Knowledge management should also be seen in a wider social and political context and not only be viewed in the context of roles played by the implementer and regulator. The RK&M project identified for instance the importance of the national curriculum to widely disseminate information and preserve the memory of a repository for radioactive waste within and across generations. Should the curriculum for the compulsory school support RK&M preservation? If so, which actors needs to be involved in this process?

Activities that support successive information and knowledge transfer

Transfer of Responsibilities after Repository Closure

For as long as the site of a long-term waste management facility is under institutional control, a successive transfer of information and knowledge across generations can, at least potentially, persist. After closure of a repository, even if there is no licensed operator for the facility, the institutional control will continue, but there might be a transfer of responsibilities [9]. This handover of responsibilities imposes a risk of losing information and knowledge [10]. Considering the amount of information and knowledge, this handover of responsibilities is a challenge, which needs to be addressed. As a ratified party to IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, Sweden is obliged to "*reaffirm that the ultimate responsibility for ensuring the safety of spent fuel and radioactive waste management rests with the State*" [7]. Clarification of the process for any transfer of responsibility at final closure is important for the continued planning of responsibilities of information and knowledge preservations in the longer term. An important step in this process, addressed in the recent government official report on potential updating of the Law on Nuclear Activities, is to clarify post-closure responsibility and its relationship to licensee responsibilities [11].

When the post-closure responsibility is determined, another question is *who* should be responsible. It's not *per se* necessary that the regulating authority to the previous licensing body should shoulder the long-term responsibility. One example how it's assured that post-closure responsibilities are met for sites containing long-lived hazardous wastes is the establishment of the Office of Legacy Management

[2] *Preserve over long periods the consolidated tacit and explicit knowledge for later reconstruction, i.e. long term knowledge preservation at a minimum level for later knowledge reconstruction* [12]

(LM)[3] in U.S. Department of Energy. LM were establishment in 2003 to meet a growing concern that even after remediating and closure of sites contaminated with radioactive and hazardous waste, many of these sites would still pose a risk to human health and the environment [12]. LM's mission statement is: "*Fulfill the Department of Energy's post-closure responsibilities and ensure the future protection of human health and the environment*." To achieve this mission, the LM have several guiding functions including:

- *Protects human health and the environment through effective and efficient long-term surveillance and maintenance.*
- *Preserves, protects, and makes accessible legacy records and information.*

Thus, there are experience with the post-closure responsibilities at sites contaminated with radioactive waste. What are the good practices to keep in mind?

Period of indirect oversight

After closure, with no licensed operations being undertaken at the repository, the period of indirect oversight[4] will commence. The duration of indirect oversight measures is impossible to foresee today, but planning needs to start in good time before closure of the facility. At the same time, it is inappropriate to be prescriptive, since technological development over coming decades can be anticipated to alter the range of possibilities. There are also other relevant factors to take into account, beyond the monitoring of environmental conditions or land use controls to protect the facility from inadvertent distribution. For example, there have been some suggestions that the international safeguards program for a repository containing fissile material could include for instance seismic, satellite and/or environmental monitoring [13]. At the same time, given that the approval for final closure of a geological disposal system will depend on evidence that its passive safety features will be functional for millennia or longer, there may be no direct technical justification from a safety perspective for post-closure monitoring of the barrier system or surrounding environment. However, post-closure monitoring activities can also be carried out to ensure transparency and to maintain stakeholder confidence in the post-closure safety [14]. This is in line with the preparatory work for the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management where several member states argued for the necessity to continue monitoring after closure and to have the capacity to implement countermeasures if an unplanned leakage were to occur, which resulted in the addition of the third paragraph to Article 17[1] [15]. Furthermore, monitoring activities will themselves support information and knowledge preservation across the generations. "Monitoring" activities can also be seen in a much wider sense; not only to observe how technical parameters evolve in relations to the disposal system and its environment, but also to monitor, for instance, that land use restrictions are followed [16].

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[3] U.S. Department of Energy, Office of Legacy Management https://www.energy.gov/lm/office-legacy-management

[4] ICRP (2013) definition of oversight [1]:

Oversight is a general term for 'watchful care' and refers to society 'keeping an eye' on the technical system and the actual implementation of plans and decisions. It includes regulatory supervision, in the form of control and inspection, preservation of societal records, and societal memory of the presence of the facility. Three time periods are considered for oversight.

- *Direct oversight refers to active control measures during the operational phase of the facility e.g. inspections and monitoring.*
- *Indirect oversight refers to measures that are used once the facility is closed and there is no longer access to the underground facilities e.g. a period of continued regulatory control, preservation of land use records, monitoring by society to check that the environmental conditions are not degrading.*
- *No oversight refers to situations when the memory of the presence of the disposal facility is lost and society no longer keep a watchful eye on the facility.*

Currently, there is no regulatory guidance in Sweden regarding what activities should be included during the period of indirect oversight or how these might differ between different radioactive waste repositories, for example for nuclear materials and those for other radioactive wastes from nuclear activities. For repositories containing fissile material, international safeguards (monitoring, nuclear material accountancy etc.) will continue to apply after closure. There is no defined time-limit concerning how long safeguards measures should continue. Treaty requirements relating to non-proliferation indicate that the termination of safeguard is determined based on when the nuclear material subject to safeguards has been consumed, diluted, or has become practicably irrecoverable [17], but guidance related to geological disposal [18] states that safeguards arrangements will nevertheless continue to apply in some form after repository closure, for as long as the treaty on the non-proliferation of nuclear weapons is in force. Thus, the longevity of international safeguards, as a form of indirect oversight, depends on future society's willingness and ability to continue safeguarding activities. Considering the diversity of activities that can be performed during the period of indirect oversight, which actors needs to be involved in the process of developing and implementing the activities? Should different repositories be treated differently?

Cultural heritage

For repositories that do not contain any fissile material, financial considerations, coupled with the dependence of an approved post-closure safety case on passive features inherent in the disposal system design, may be factors that limit the extent and duration of monitoring activities after final closure. This can give rise to a conflict if the preference of stakeholders is for monitoring to continue as an integral component of society's indirect oversight. But a commencing conflict between stakeholders and authorities responsible for post-closure measures is not *per se* a disadvantage from a RK&M perspective. It may, for example, contribute to preserving the memory of the site and what is buried at depth through creating a heritage of the site [19]. It is, perhaps, the cultural heritage factor that on the longest timescales has the largest possibility to preserve the memory and legacy of the repository. Even if no major future discontinuities occur, it may be that future intentional or unintentional loss of institutional memory is inevitable due to the safety measures taken in the past.

Cultural heritage is therefore a factor than can contribute to preserving RK&M relating to a repository, albeit not according the present generation's intentions, but as an inheritance for future generations to attend to and reinterpret. Can the regulatory framework support promoting the cultural heritage associated with the nuclear legacy? Which actors could play a role in this respect?

Activities that support direct information and knowledge transfer

So far, the primary focus in this text has been on institutional arrangements for the *successive transfer* of information and knowledge, in which the strategy for presentation of records, knowledge and memory relies on an unbroken link between the generations. An unbroken link implies that information and knowledge is constantly maintained, reworked and updated in order to be able to exploit it and keep it accessible (knowledge and records), readable and understandable (records). Enabling successive transfer is therefore an important element in long-term RK&M preservation. Another strategy for maintaining RK&M relies on transferring the present information and knowledge directly to a future receiver [20]. Such an approach depends on *conserving* information and knowledge from a certain point in time to a distant future, when it may be retrieved and understood. This can involve making information available in the form of markers[5] or within time capsules. Various

[5] As defined in the RK&M project. *A long-lasting object that indicates an area of influence, power or danger. It is placed strategically at or near the site for immediate recognition or for discovery at a later time.*

designs, with different purposes, have been discussed (see e.g. [21]). A potential advantage of such direct transfer strategies is that they have the potential to conserve the information and knowledge about the repository for very long time scales without depending on intergenerational transfer. Thus, for example, discovering a marker or time capsule during the period of no oversight[4] could at least help to restore the memory of the presence of the disposal facility. The reliability of direct transfer is, however, hampered by uncertainty surrounding the readability and comprehensibility of the conserved information and knowledge to a future discoverer. This, in turn, raises the concern that misinterpretation of markers or other methods of direct information transfer (symbols, icons, time capsules etc.) could itself lead to intrusion without clear understanding of its potential implications. A decision regarding whether or not to include direct transfer of information and knowledge in the framework for preservation of RK&M therefore invokes consideration of moral obligations [20]. The question of imposing a loss of institutional memory rather than planning for remembrance has been discussed in the NEA project records, knowledge and memory (RK&M) [5]. In this study it was concluded that the ethical principle of supporting informed decision making over time, giving future generations the freedom of choice over what to do with such information, is an essential factor in determining which path to choose.

In its safety requirements for disposal of radioactive waste [22], IAEA notes (requirement 22: the period after closure and institutional control) that marking a disposal facility for radioactive waste with durable surface and/or subsurface markers can reduce the risk of intrusion and that such measures are therefore among those to be considered in planning for future control over the site. The American Code of Federal Regulations relating to protection of the environment states more prescriptively that disposal of spent nuclear fuel or high-level or transuranic wastes [23]:

> *"[...] shall be designated by the most permanent markers, records, and other passive institutional controls[6] practicable to indicate the dangers of the wastes and their location".* § 191.14(c)

> *"Any compliance application shall include detailed descriptions of the measures that will be employed to preserve knowledge about the location, design, and contents of the disposal system. Such measures shall include: (1) Identification of the controlled area by markers that have been designed and will be fabricated and emplaced to be as permanent as practicable [---]"* § 194.43(a)

There is currently no specific regulatory guidance in Sweden regarding the direct transfer of information and knowledge to a future receiver in relation to waste disposal. The strategy of direct transfer can be regarded as controversial since its added value to RK&M preservation is difficult to assess. Furthermore, there is no straightforward definition of how this should be done and some methods of direct transfer, such as building large monuments or large time capsules, can involve high development and implementation costs. Nevertheless, it is relevant to consider whether such an approach to information and knowledge preservation over generations has a part of play in increasing redundancy and thereby increasing the possibility of successfully supporting informed decision

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Commentary: A marker is an object meant to reach out to future generations in the medium to long term. Any marker is conceived to be immobile (i.e., in permanent association with a site), robust, in order to maximize survivability on its own, and to provide messages designed to be understandable across generations [5]

[6] Passive institutional controls means: (1) Markers, as permanent as practicable, placed on the Earth's surface; (2) Public records and archives; (3) Government ownership and regulations regarding land or resource use; and (4) Other reasonable methods of preserving knowledge about the location, design, and contents of the Yucca Mountain disposal system. § 197.12

making over time., it needs to be explored how the regulatory framework can support strategies for direct transfer of information and knowledge. Equally important is to explore how this direct strategy can be integrated in a societal context. Which actors could play a role in this respect?

The broader Swedish regulatory context

The focus of this text has been on the regulatory framework for the preservation of records, knowledge and memory regarding repositories for radioactive waste. However, RK&M preservation over generations is similarly important at other disposal sites containing, for example, non-radioactive, long-lived hazardous wastes or potential injection sites for carbon dioxide storage. For example, a Swedish government official report regarding geological repositories for long-lived hazardous non-radioactive wastes, predominantly mercury and mercury-tainted waste, states that such a facility should be designed and localised whith the aim of decreasing the possibility of future inadvertent human intrusion. In addition, the documentation regarding the facility's location, design and inventory needs to be preserved [24]. Such guidance is very similar to that given in SSM's regulations for the final management of spent nuclear fuel and nuclear waste [2], highlighted earlier.

Thus, a range of different actors, such as policy makers, regulators, implementers, environmental groups, local communities, researchers etc., have a common interest that would benefit from a holistic and systematic approach to RK&M preservation. Preparation of regulations that support RK&M preservation therefore needs to be coordinated between many actors working in different fields of safety and environmental protection. Consideration also needs to be given to on which level specific regulations relating to RK&M preservation could be developed with regard to frame law, supplementary ordinances and administrative provisions that would define the regulatory guidance (frame law). The first step towards a holistic and systematic approach would be to identify the key actors in developing regulatory guidance on RK&M preservation regarding disposal sites containing long-lived hazardous wastes. What other waste categories need to have a long-term preservation strategy of records and knowledge for future generations, i.e what other waste categories falls under the ethical principle of avoiding an undue burden on future generations?

Conclusion

Regulatory guidance regarding obligations in relation to the preservation of records, knowledge and memory relating to a geological disposal facility should encompass *what* measures needs to be taken, *when* then should be taken and *who* should implement them for the period of indirect oversight. An important step in this process, addressed in the recent government official report on potential updating of the Law on Nuclear Activities (SOU 2019:16), is to clarify post-closure responsibility and its relationship to licensee responsibilities. The RK&M project has highlighted a multidisciplinary and participatory process as a key factor for RK&M preservation. The creation of a regulatory framework to support RK&M preservation is no exception to this. Several questions have been raised in the text that will need to be addressed through such a participatory process in continued work relating to the definition and implementation of a national legal framework to support long-term RK&M preservation. One recurring practical question is how to identify and involve different actors in this implementation process, taking into account similar concerns for long-term safety and environmental protection related to other forms of waste disposal.

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Appendix 1 Regulatory articles of Sweden

Ordinance with instructions for the Swedish Radiation Safety Authority (SFS 2008:452)
Regulations concerning safety in nuclear facilities (SSMFS 2008:1)
Regulations concerning the protection of human health and the environment in connection with the final management of spent nuclear fuel and nuclear waste (SSMFS 2008:37)
Regulations and guidelines with regards to requirements for proper filing, archiving and long-term preservation (SSMFS 2008:38)
Regulations and guidelines for planning, implementation and operation of the premises for archives (RA-FS 2013:4)
Regulations governing the production, handling, keeping and delivery of documents on paper (RA-FS 2006:1) and Regulations governing changes in regulations governing the production, handling, keeping and delivery of documents on paper (RA-FS 2010:2)
Regulations governing the production, keeping and delivery of electronic documents (RA-FS 2009:1-2)