

Preservation of Records, Knowledge and Memory across Generations (RK&M)

A Literature Survey on
Markers and Memory
Preservation for Deep
Geological Repositories

NUCLEAR ENERGY AGENCY

Radioactive Waste Management Committee**Preservation of Records, Knowledge and Memory across Generations (RK&M)****A Literature Survey on Markers and Memory Preservation for Deep Geological Repositories**

This study was originally commissioned by the Swiss Federal Office of Energy between 2008 and 2010. The intention was to investigate the 'state of the art' on marking with a view to learning lessons for geological repositories.

The "Preservation of Records, Knowledge and Memory across Generations (RK&M)" project of the OECD Nuclear Energy Agency (NEA) found that providing such a study to a wider, and not only German speaking audience, could be very useful, and offered the platform for the publication of the English translation.

It should be stressed that the present literature study does not seek to provide directly usable solutions in terms of marking, labelling and archiving. It is designed mainly to inform the various bodies responsible for radioactive waste disposal, national institutions as well as a wider interested public and to convey the complexity of the topic and the variety of issues that have to be addressed in the future.

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Research Programme on Radioactive Wastes

**Literature Survey on Markers and Memory Preservation
for Deep Geological Repositories**

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Foreword

This study is an English translation and slight update of a previous study by Marcos Buser on behalf of the Swiss Federal Office of Energy.

When the expert group "Concepts for Radioactive Waste" (EKRA) proposed the conceptual bases for the Swiss waste management programme over a decade ago, it also recommended to start research on marking nuclear waste sites and to promote, at the same time, an independent research programme supported by the regulators in these very complex technical and social areas. Both recommendations were taken up by the Swiss Parliament and enacted into Law as the Nuclear Energy Act of 2003. The later decision of the Swiss Federal Office of Energy to promote a literature survey on the state of the art of marking programs of geological repositories was specifically based on this law.

Mr. Buser was asked to perform this study because of his training as a geologist and social scientist, his long and wide experience in the field of nuclear waste management, and the different interdisciplinary studies he had published already. The original study was carried out over a two-year period. It assembled the knowledge of the various marker projects that had already been developed around the world and placed this information as well in an archaeological, historical, or semiotic context.

The reception of the study was wide-ranging. The author received many requests from universities, research groups or institutions that dealt with this or similar issues and for which such a study offered much usable material. The media also showed a keen interest in the study and its results. For almost three years, the author was regularly invited to radio and television interviews, as well as to panel discussions in German speaking areas. Numerous articles have also appeared in the press.

The "Preservation of Records, Knowledge and Memory Across Generations (RK&M)" project of the OECD Nuclear Energy Agency (NEA) found that providing such a study to a wider, and not only German speaking audience, could be very useful, and offered the platform for the publication of the English translation. The Federal Office of Energy agreed to such a publication. Nagra, the Swiss implementer of deep geologic repository of radioactive waste, kindly financed the translation of the study into English. Thus, the literature survey on markers can now be provided to a wider circle of researchers and interested parties.

Compared with the original German version, some important changes should be noted. Namely, (a) some illustrations and tables have been added; (b) a few clarifications to the text have been made, thanks to comments by attentive readers; (c) the list of references has been augmented by a few entries. The title of the study has also been changed and now better represents those contents to be examined as part of the "Preservation of Records, Knowledge and Memory Across Generations" project of the NEA. The chapter on the status of each country's markers project was left out from the English version, as more up to date information can be obtained from the NEA RK&M project.¹

It should be stressed that the present literature study does not seek to provide directly usable solutions in terms of marking, labelling and archiving. It is designed mainly to inform the various bodies responsible for radioactive waste disposal, national institutions as well as a wider interested

¹ <http://www.oecd-nea.org/rwm/rkm/>

public and to convey the complexity of the topic and the variety of issues that have to be addressed in the future.

Acknowledgments

Marcos Buser and the OECD/NEA wish to express their gratitude to the Swiss Federal Office of Energy and to Nagra for their support translating the original German version into English. Many thanks are also due to RK&M project members who reviewed the report and provided comments for the current updated version.

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Executive summary

This study was originally commissioned by the Swiss Federal Office of Energy between 2008 and 2010. The intention was to investigate the 'state of the art' on marking with a view to learning lessons for geological repositories. This is an edited and slightly updated English translation, published by the NEA as part of the RWM project 'The Preservation of Records, Knowledge and Memory (RK&M) across Generations'.

The work is conceived as a literature study. It considers over 150 texts, published between 1928 and 2013. Texts published between the 1990 and 2010 form a majority, making the 1990s and 2000s the dominant era. The texts include technical reports, journal articles, conference proceedings, implementation plans, national regulations, and full-length books. Some publications are specifically about the concept, implementation and requirements for Markers. Others consider the geological disposal of radioactive from other points of view – for example, archiving, or intrusion scenarios. Others are publications on history or futurism, including histories of genocide and language, and the possibilities of communication far into the future.

Authors of the texts include academics, international organisations, consultants commissioned by national organisations, regulators, implementers, and protest groups.

It should be recognised that, whilst care has been taken to provide a wide and representative study, the concept of 'marking' a geological repository was first established in the USA. The available literature on Markers is still dominated by work carried out in the USA in the 1980s, 1990s and 2000s. The conclusions and points of view surveyed are therefore weighted towards this body of work.

The study brings together the knowledge and experience from the field of marking and archiving from the last few decades and provides an overview of the present status of discussions on the topic. It is an interdisciplinary study and covers as wide a range as possible of the perspectives from which marking needs to be considered – that is, safety, risks, the technologies to be used, and the possibilities for communicating with future generations. These deliberations should highlight the problems, strengths and contradictions associated with marking. 28 different topics were selected; these are summarised into six topical blocks:

- Block 1: Fundamental Questions on the Topic of Marking (questions 0)
- Block 2: Questions on Humans and Society (question A)
- Block 3: The Environment and Underground Space (questions B)
- Block 4: Marking and Structures (questions C)
- Block 5: Transmitting Information over Time (questions D)
- Block 6: The Susceptibility to Failure of Marking Systems (questions E)

Each of these blocks is introduced by briefly presenting a potential problem and questions in the technical literature are then addressed. Each of these is then considered briefly from the personal viewpoint of the author.

What is novel about this study is the perspective from which marking or safety is considered. It looks at the possible driving forces behind human and social actions that could influence marking programmes or make them superfluous.

It is notable that the same thoughts voiced by specialised institutions, bodies and authors as well as laypersons are raised repeatedly in the literature, which suggests that the key safety problems and the most important weak points in communicating over time have largely been identified. It is the opinion of the author that knowledge from history and society should have a corrective influence on current repository concepts and projects in the different countries using nuclear energy. One concept to note is humanity's propensity to recycle, as examined by Poeschke and exemplified in the study (figures 4.5 and 4.6). This suggests the possibility of future generations re-appropriating the materials used to construct the repository or markers, as well as being concerned with the radioactive waste stored in the repository.

Block 1: Fundamental Questions on the Topic of Marking

The result of the study shows that, when dealing with the major fundamental questions of the sense of markers, all authors agree that marker programs should have warning functions. In addition, some authors realized that a 'memory culture' was needed in order to keep alive awareness of the repository, as the NEA already recommends. Some scientists recognize that communication of warnings to the distant future will bring a new dimension in dealing with the future, and that very large structural and economic challenges may be associated with it. Many authors have already given some thought to what information should be passed on to future generations, even if different ideas and approaches are being pursued. Finally, some authors point out the difficulties of this information transfer, and indicate that information can be misunderstood outside of a closed community or in a changed context.

Block 2: Questions on Humans and Society

In relation to the role of man and society, various authors have asked to whom the warnings should be addressed in the future, and have offered a range of ideas. There is some consensus on the question of for how long memory preservation should be designed to last. Generally the opinion is that a warning message should be designed to last for around 10,000 years, although there is little justification in the literature for selecting this timeframe. Questions dealing with technology development such as new burial techniques during the intended period of memory preservation are much more difficult to handle. Despite numerous historical examples the question remains open if warnings about the future can ever find attention, and the risks of intrusion and exhumation are discussed by many authors.

Block 3: The Environment and Underground Space

A series of questions deals with changes in the environment at the surface during the projected timeframes for the markers. Many authors have recognized the problem of the durability and stability of substrates of information. Here very concrete suggestions as to which materials are suitable for this purpose and what developments are desirable have been discussed. The question of whether a repository should be actively forgotten – that is, hidden or camouflaged so that it will be forgotten - has also been addressed. Technology is shown to play a decisive role in whether camouflage is at all possible. Measures put in place to prevent intrusion into the repository are primarily designed to protect societies who have lost the technological capacity to manage the consequences of drilling into the repository.

Block 4: Marking and Structures

Concerning the marker techniques on the surface as well as in the whole repository, it is generally accepted that markers are well protected in the repository itself, whereas the developments at the surface can be very different due to climatic or social factors. There are a variety of papers that describe marker systems and protective barriers at or near to the surface. Questions concerning the durability of such marker systems are also discussed. Some authors emphasize the need of marker techniques between the deep repository and the surface in order to reduce the risk of intrusion.

Practically all authors come to the conclusion that markers alone cannot prevent the intrusion into a repository.

Block 5: Transmitting Information over Time

It is generally agreed that active measures are necessary for the preservation of knowledge. The large number of available documents and data raises the question of what should be transmitted in what kind of form. These questions are investigated by numerous authors, but the long-term archiving of documents has not received much academic attention in the papers included here. Several authors note that, given the shift in the cultural worlds of experience, the techniques of information transmission represent a particular challenge in the field of nuclear waste disposal. Several authors have discussed the techniques and problems of information transmission through language and character. A consensus about the semiotic challenges of information transfer has not been reached. Several researchers have also written about the structures that are required to transmit information from generation to generation.

Block 6: The Susceptibility to Failure of Marking Systems

The loss of information has so far been only sparsely illuminated, although it is universally acknowledged that information can be lost. Individual authors have demonstrated this problem via shifts in the understanding of information over time. It turns out that many sources of error are present, by which information may be lost - through conscious as well as unconscious actions. In addition, historical analyses show that information and information transfer through history can be intentionally manipulated, especially when the control of this information is centralized.

The literature study shows that technical questions concerning markers and to some extent archiving have largely been raised and discussed, but questions on how to implement marking and archiving are less well established. The lack of consensus in this area indicates that there is scope for further research into how to implement different marking and archiving concepts.

1. Introduction

Technical concepts for the management and disposal of radioactive waste had already been developed by the late 40s and 50s of the last century. The spectrum of solutions considered was very wide from the beginning; besides the classical concept of final disposal in deep geological formations, it included strategies such as injecting liquid wastes into unused boreholes, diluting liquid wastes in the sea, disposing of waste in a desert environment or placing it in the ice of the South Pole. With time, however, it has become clear that deep geological disposal is the only strategy that can realistically be implemented and that is capable of providing the required level of safety over the long containment times. This is the strategy that is pursued worldwide today.

In parallel with these developments, other issues have been the subject of increasing attention since the 1970s, for example the retrievability of waste, monitoring of repositories and the political and social influences of such disposal concepts. With ominous titles such as “Warnings for the distant future”, the communication of information on risk-related technologies to future generations also entered the discussion arena. The intention was to look at this issue in more depth over the years and to make concrete the details for actual sites or disposal programmes. In Switzerland, publications addressing this topic appeared in the 1980s and 1990s. The Expert Group on Disposal Concepts for Radioactive Waste (EKRA) set up by the Federal Department of the Environment, Transport, Energy and Communications (DETEC) included the question of marking repositories in its recommendations for an independent research programme (EKRA 2002). In the context of implementing this programme, the Federal Office of Energy set up a working group to identify the focus of the research topics. Based on their recommendations, the topic “Marking and Knowledge Preservation” was included in the list of key research areas (Arbeitsgruppe Forschungsprogramme 2008).

The issue of marking is a driving force in the discussion surrounding geological disposal. A key question that arises repeatedly in the literature, and which is always the subject of controversy, is whether marking can actually perform the hoped-for function of warning future generations. This highlights the fact that there are various arguments both for and against marking and reflects the difficulty of finding coherent answers to the questions posed.

The aim of this study is to provide an overview of the current status of science and technology in the area of marking and knowledge preservation and it was originally intended to provide the basis for the discussions on how Switzerland should handle these issues. It begins by looking at the question of what marking should fundamentally be capable of doing and what tasks it can or must fulfill. It then discusses what conditions have to be considered for preserving knowledge over the long timescales involved in waste disposal. Also important in this respect is the question of how long marking can remain meaningful or functional.

The report is structured as follows: Chapter 2 outlines the geological disposal system and its changes over time. Based on this rough outline, Chapter 3 sets out the fundamental questions that have to be considered in deciding whether a marking project is meaningful for a repository or not. Chapter 4 attempts to evaluate some of the published literature in the light of these questions. Finally, Chapter 5 gives initial answers to the question of the direction in which the discussion surrounding marking could evolve.

2. The system: predictability of change and methodical questions

Some of the most fundamental questions posed by individuals and society relate to the future. In fact, knowing what the future will bring requires a particularly high human capacity for abstraction regarding the possibilities of how the future could develop. Experiments have shown that the ability to comprehend future time periods is very restricted in animals (minutes, hours, possibly days). Only man is capable of conceiving of times far beyond his death. From this ability, which is unknown in the animal world, comes the desire to know the content of these future time periods and how they will evolve. The origin and existence of prognostics lie in man's deep-seated wish to be certain about future events. This brings us to the starting-point for the topic of marking, namely the extent to which change is foreseeable and whether knowledge can be transferred over the extremely long time periods required to ensure the safety of humans and the environment. Added to this is the question of what conditions have to be met for such an undertaking to be successful.

Answering these questions requires information on how a system as a whole or its sub-systems could change during the course of time. Understanding the processes involved in these systems or sub-systems and the rates at which they occur, as well as putting them in context, is one of the fundamental requirements for determining the direction and rate of change. It is therefore attempted in the following to identify and characterise the key features of the deep geological disposal system, particularly in terms of the alteration processes and rates of the sub-systems over time.

Figure 2.1 is a schematic representation of a geological repository at the present time (t_0) and in the far future (t_1). Five sub-systems are distinguished that are subject to change with time:

- Humans and society, with all their actions and activities, which also include development of science and technology. Humans and the environment have to be protected from the hazards associated with a repository and, at the same time, prevented from putting the repository at risk.
- The environment (bio-, hydro- and atmosphere), which can have a strong influence on the susceptibility of social systems to crisis situations.
- The underground geological environment and its specific characteristics (stratification, tectonics, etc.) and its potential changes, which could affect the safety of the geological repository and its marking system.
- The structure known as the deep geological repository which contains the waste and has special structural features (shafts, tunnels, seals, etc.); the properties of the radioactive waste and its effect on living cells determine the timescale over which the marking system has to remain functional.
- All potential marking technologies that come into consideration for a repository, be it structural or technical components in the repository itself, at the surface or in societal communication systems.

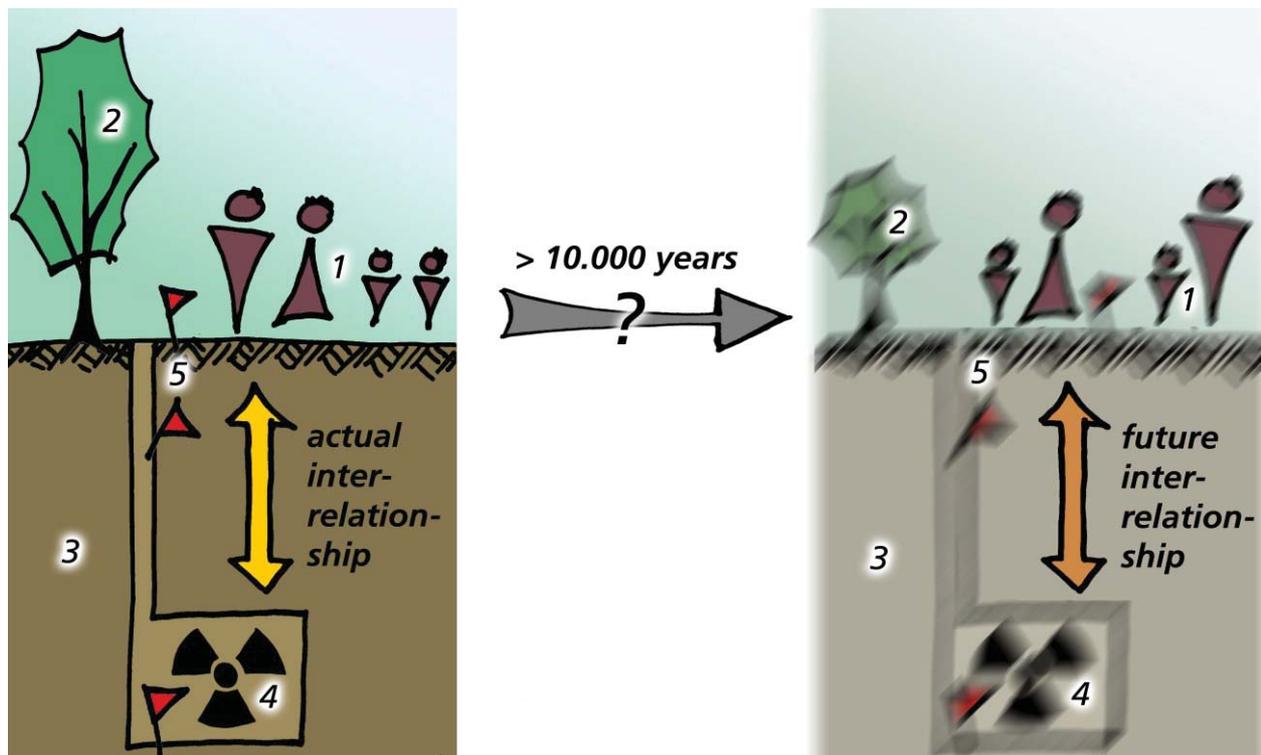


Figure 2-1: Schematic representation of a deep repository today (t_0) and in the distant future (t_1) and definition of five sub-systems for determining change with time

Sub-systems considered:

- 1 Man
- 2 Environment (biosphere, atmosphere, hydrosphere)
- 3 Host rock and geology (lithosphere)
- 4 Facility (deep repository with waste)
- 5 Marking (elements of the repository or elements in the environment as long-term warning measures)

The success of a repository marking system depends on the evolution of these five sub-systems, which change in different ways. While most geological processes are perceived by humans as occurring very slowly, changes in social systems are relatively fast. Social changes are often driven by technical innovation and take place rapidly, making them difficult or even impossible to predict. Biological systems also react relatively quickly, even in the case of human evolution. Based on the most recent findings from the fields of anthropology and neurology, evolutionary processes show that various human species have come and gone in the last million years (Figure 2). Modern man (*Homo sapiens sapiens*) is the last biological step to date in the evolution of hominids. Over the long time periods that have to be considered for waste containment, it is right to ask whether *Homo sapiens* will still be there when the radioactivity in the repository has largely decayed away. The application of increasingly sophisticated medical technologies to the human body could greatly accelerate this process through genetic procedures, implantation medicine or other applications.

In natural systems – from the atmosphere through the hydrosphere to the lithosphere – processes occur at different rates. While climatic and water cycle processes are relatively rapid, processes in the earth's crust occur – with a few exceptions – extremely slowly in terms of human perception. Process rates often far below centimetres per year are the rule for large-scale movements or those in the deep underground environment. In comparison, changes in the human environment, particularly societal changes, occur extremely quickly, even if certain laws governing human action can be derived from history. One exception is technical change in recent years, which cannot really be predicted over longer times.

These different processes and process rates raise the question as to what type of marking system could be relevant for a repository and over what timescale. Marking systems could be perceived differently over different time spans and under different social conditions. In times of crisis, a repository and its marking system will have a different value or status compared to times of excess and risk mitigation. In this way, surface marking could come to have a different meaning. Marking underground is exposed to a significantly smaller number of changes than at the surface. The hazard presented by radioactive waste also decreases with time, meaning that the marking could lose its significance. The alternative case should also be mentioned, where the hazard from the geological repository has been eliminated but the marking still remains. Ultimately, it has to be asked how long marking is actually necessary or desirable. Should it continue to the end of the time when the waste presents a hazard? Can a time period similar to that since the Neolithic Change² be justified? Or is the timescale up to the advanced civilisations of Mesopotamia such as Sumer and Akkad in the fourth and third millennium BCE decisive? All these considerations highlight the fact that marking systems should be differentiated not only in terms of content - the timescales and the lifetime of the individual markers should also be included in the deliberations.

² Neolithic Change or "Revolution": around 10,000 to 12,000 years ago, the start of an increase in settled communities, together with development of new and more efficient economic systems.

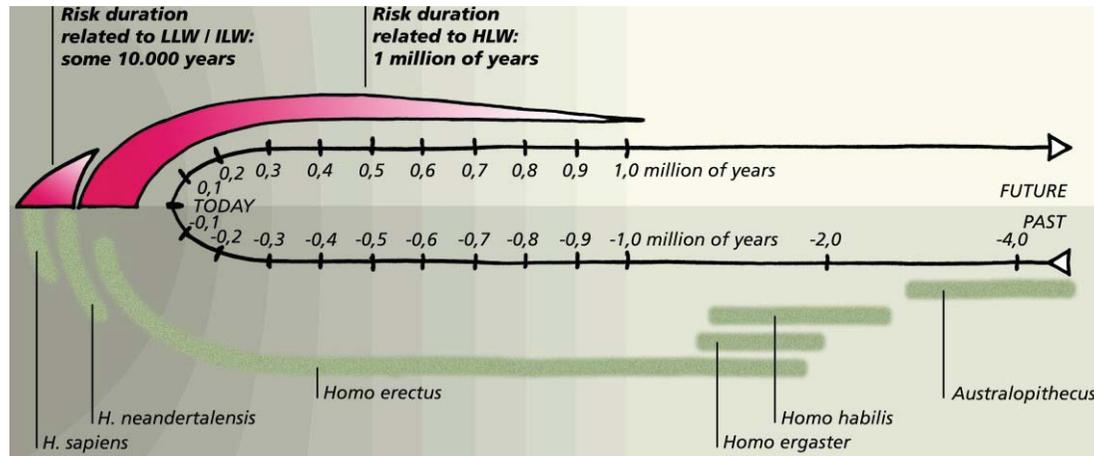


Figure 2-2: Timescales for evolution of hominids, historical milestones in human evolution and risk timescales for waste repositories

Future event	Time (years)		Past event
Drainage of contaminated water from waste disposal sites no longer functional	100	100 ago	Becquerel discovers natural radioactivity (1896), first offshore boreholes for oil exploration (1900), Russo-Japanese war (1905), start of WW1 (1914)
Time period for a first risk assessment (e.g. Riet waste disposal site Winterthur)	200	200 ago	First gas lamp (1792), Goethe's Theory of Colours (1810), Age of Enlightenment, Napoleonic era
Engineered barriers of disposal facilities conforming to the TVA (Swiss technical waste ordinance) no longer functional	400 to 800	400 to 800 ago	Age of Galileo and Kepler (around 1600), Edict of Nantes (1598), Cathar crusades (beginning of 13 th century)
Ion-exchange capacity for the bioreactor compartment at the Feldmoos disposal facility (ZH) exhausted	2500	2500 ago	Greek water clocks; steel production in India; whale oil lamps with asbestos wicks in China, Greco-Persian wars, start of the heyday of Hellenism
		9000 ago	Stone Age temple of Göbekli tepe (Urfa, Anatolia)
Ion-exchange capacity for the inert materials compartment at the Feldmoos disposal facility (ZH) exhausted	30,000	30,000 ago	Upper Palaeolithic, use of strokes (groups of 5) for counting (e.g. herds); Neanderthals die out
		37,000 to 43,000 ago	First identified Neanderthal jewellery; Homo sapiens first identified in Europe; Palaeolithic (Old Stone Age) flutes found in the Swabian Alb (37,000 years ago)
		50,000 ago	Identification of humans similar to Homo erectus in south-east Asia
		40,000 to 70,000 ago	Neanderthals bury their dead, obtain birch pitch by distillation
		65,000 to 70,000 ago	Migration of Homo sapiens from Africa
Maximum isolation period for L/ILW	Up to 100,000	100,000 ago	First find of Homo sapiens jewellery and of burials by Homo sapiens
Isolation period for HLW	Up to 1 million	~ 1 million ago	First and last identification of Homo heidelbergensis (800,000 and 200,000 years ago)

3. Fundamental questions and procedure for analysing the current status of knowledge

In order to record the current status of knowledge on the topic of marking in the areas of science, technology and society, a selection of questions is compiled for the purpose of evaluating the published literature. A distinction is made between general questions on the intentions and objectives of marking (section 3.1) and questions on specific sub-systems (section 3.2).

3.1 Fundamental questions on the intentions and objectives of marking

- 01 *Why should marking be used? Or in other words: what reasons can be given for justifying or rejecting marking?*
- 02 *Under what conditions is it possible to warn future generations?*
- 03 *Is marking possible at reasonable cost?*
- 04 *How far should we go to protect future generations?*
- 05 *What information should be handed over to future generations?*
- 06 *Are the potential for misinterpretation, manipulation and/or susceptibility to errors or perturbations of the marking system recognised as significant elements?*

3.2 Questions on the specific sub-systems

A Humans and society

- A1 *Who is marking aimed at in the future (primitive society or highly civilised culture, etc.)? Are evolutionary aspects considered in the literature on marking? Can processes and changes of this type even be recognised (e.g. scenario analyses)?*
- A2 *How long should marking remain in place? Are different marking technologies foreseen for different risk situations?*
- A3 *What role do technology and technology development play in marking?*
- A4 *Who should be responsible for marking? What structures are important for long-term management of safety? What structures / organisational features could be necessary after the closure of the facility (legal title, responsibilities)?*
- A5 *What motives for intentional / unintentional exposure (exhumation) of the waste have to be considered?*
- A6 *To what extent can the history of science and technology contribute to clarifying the question of the purpose of marking (particularly whether the question of the sense of marking is actually superfluous as the construction of the shaft and surface facilities already constitutes marking)?*

B Environment (biosphere) and underground (lithosphere)

- B1 *What changes in the environment and at the earth's surface have to be taken into account during the required waste containment period?*
- B2 *Can environmental and societal crises be sufficiently well assessed (historical studies) and extrapolated to make them relevant for the issue of marking?*
- B3 *What changes in the earth's crust could affect the integrity of the facility and its marking system (processes and properties)? In what way do the relevant sub-systems change: can we predict these changes sufficiently accurately based on historical studies and models? Are changes deep underground over the time period for waste containment relevant for a marking system?*
- B4 *Is it possible to camouflage and close a repository in such a way that any reminder of its presence is permanently removed?*

C Marking and facility

- C1 *Can the evolution of the repository system (natural and historical analogues, scenario analyses, etc.), and hence its potential impact on a marking programme, be estimated?*
- C2 *What intrusion scenarios have to be considered for a repository (hazard analyses) and what marking measures are conceivable in this context? What marking technologies are foreseen for protecting the facility and its inventory from intentional intrusion or planned destruction, e.g. for targeted retrieval?*
- C3 *What is the status of technology with respect to marking at the surface and in the repository itself? Can the lifetime of different technical markers (physical, chemical, biological, etc.) be realistically estimated?*
- C4 *Should waste packaging (e.g. canisters) and disposal caverns be used as marking elements?*

D Marking and information

- D1 *How can active and passive marking systems be distinguished? Have active marking technologies and systems for handing down information been surveyed systematically in all possible areas?*
- D2 *What should be transferred and how? What creative possibilities are offered by marking at the surface in a large area above the repository (macro-level)? Can such an arrangement be handed down in a way that is time-invariant?*
- D3 *What technologies are foreseen for knowledge transfer (knowledge management, trading technologies, codification technologies, etc.)? How can the stability of these technologies over time be estimated today?*
- D4 *What social structures have to be considered for concrete transfer of knowledge on the repository? Is experience with historically stable structures (e.g. institutions, bodies) relevant in this context? Can local associations perform the "memory" function over long time periods?*

E Susceptibility of the marking and knowledge transfer system to errors and perturbations

- E1 *What requirements have to be met to ensure that communication does not fail over time? Can risk catalogues adequately capture and describe the potential methods of failure?*

- E2 *To what extent can marking systems be repaired and/or corrected (maintenance)? How susceptible to errors are marking systems?*
- E3 *What requirements have to be met for deciphering marking and knowledge transfer systems (information media, structural requirements, encoding and decoding systems, etc.)? How great is the potential for misinterpretation of marking systems? Can marking put a repository at risk? In other words, could it lead to deliberate clearing out of a repository?*
- E4 *Are the relay structures for long-term transfer of information sufficiently secured against loss and distortion processes? Can manipulation of such structures be prevented?*

4. Fundamental questions for analysing the current status of knowledge

The questions raised in Chapter 3 are all treated in the same way:

Problem definition

The problem or issue is described as accurately as possible and specified in such a way as to allow the literature to be evaluated in a targeted manner. Importance is attached to presenting the literature information without any personal interpretation or evaluation.

Evaluation of the literature

The evaluation of the literature proceeds as follows

- The first step is to bring together standard works that have dealt with the topic of marking of deep repositories. These include reports by repository implementers or international bodies such as the International Atomic Energy Agency (IAEA) or the OECD Nuclear Energy Agency (NEA). Literature references in these documents are also taken into consideration. The evaluation covers the literature in the area of marking comprehensively, even if not all projects can be considered to the same extent. For example, the marking projects for the US “Waste Isolation Pilot Plant” are given significantly more attention than the later projects at Hanford and Yucca Mountain.
- To supplement the above, manuals and technical works, compendia and syntheses and, to some extent, articles in the technical literature in areas such as archaeology and history, semiotics and linguistics, religion, philosophy or economic sciences and organisational sociology are evaluated. Many of the cited documents belong to recognised standard works. The study covers only a small proportion of the existing material and articles on a range of topics, but the knowledge that can be derived from these works is sufficient evidence of the experience that has been gained. Where necessary, specific literature research was carried out on individual questions.

Appraisal

The appraisal contains a brief summary of the main thoughts of the author, with the most important conclusions derived for the question block. The author also attempts, where possible, to answer questions and identify open issues.

4.1 Protection objectives and motives for intrusion into a repository

Before the question of marking is investigated in section 4.2 and subsequent sections, the potential interests of a future society in a repository should be clarified, as should the links to be established between the repository and society. The concrete question is what attitudes a society or individuals in that society could adopt towards the repository and how these could develop over time. Such

deliberations form an important basis for deciding whether or not marking programmes can ultimately be implemented.

The basis for these deliberations is provided by the hazard potential of the waste and the ethical imperative to protect future generations from the harmful effects of the repository. This protection extends not only to passive or naturally occurring hazards due to transport of radiation to the human environment, but also to active hazards such as human intrusion into the repository by future generations.

There are different backgrounds to the motive for intruding into a repository (see Table 4.1). A number of these motives are considered without making any claim to covering all the driving forces behind human action. These are commented on briefly in the following:

- Greed: Greed is one of the most powerful driving forces and can be traced from looting and pillaging in ancient times through raids during world colonisation to the wars of recent times (looting of cultural possessions, blood diamonds, etc.). In its modern form, it finds expression as avarice, for example raids on the stock markets (Galbraith 1992, Galbraith 2005a, Galbraith 2005b) or treasure-seeking and plundering of shipwrecks or treasures hidden in the earth (cf. companies such as “Odyssey Marine Exploration” that are quoted on the stock exchange).
- Adversity: Adversity has a similar basic rationale to greed, i.e. it is based on material needs. However, the driving force here is not short-term gain, but the specific search for re-usable goods that can relieve economic hardship. Examples from recent times include the increasingly common accidents worldwide with theft of radioactive sources, for example from old hospitals (IAEA 1988, IAEA 2001, IAEA 2002).
- Curiosity: History and archaeology are strongly linked with curiosity. In such cases, the thirst for knowledge is often in the foreground, but so too are personal ambition and the search for fame. The history of the discovery of archaeological finds bears witness to this, already from ancient times. Archaeological history also reveals a further interesting phenomenon – many major finds were discovered by systematic scanning of the earth’s surface.
- Maximising gain: This scenario is basically about the targeted retrieval of usable or valuable materials. It cannot be ruled out, particularly if metals such as copper – which has been mined and used by many cultures since the Bronze Age - are involved. Fissile materials could also be used as fuel.
- Sense of responsibility: This motivation implies taking measures to counter the potential negative consequences of social actions. It is something that can be observed in all stable societies. In the worst case, namely leakage from a repository, it is likely that future generations will take clean-up measures (e.g. as for the contaminated sites at Bonfol and Kölliken in Switzerland today).
- Herostratism, wantonness, fanaticism: Since Herostratus destroyed the Temple of Artemis in Ephesus in 356 BCE to secure fame and Nero started the Fire of Rome in the year 64 AD, even the last 100 years have provided plenty of evidence of herostratic madness and ideological fanaticism (e.g. Hitler’s command in 1944 to completely destroy Paris, cf. von Choltitz 1950; the Cultural Revolution in China; destruction of non-Islamic cultural possessions by radical Islamic forces). However unlikely it may seem today, this mainspring of human unpredictability should be included in the list of threats to a repository.
- Lack of interest: Lack of interest can be understood as an attitude in which mainly immediate relationships to one’s own life are perceived and lived (self-interest). In this sense, lack of

interest is a key motivation in the context of repositories that strongly supports the possibility of the facility being forgotten.

- Negligence: Negligence has similar roots to lack of interest and can also be seen as a preliminary stage to forgetting a repository. Negligence also means a shift in perception of hazard - one begins to live with the risk and becomes used to it.

	Risk type	Driving force for action or reasons for non-action	Risk perception	Form of realisation	Protection factor (effect) of a marking programme on intrusion
1	Greed	Ruthless profit-orientation of individual interests (speculative investors, example "stock market" or "treasure-hunting", see point 4)	Tends to be low as profit orientation dominates and strongly influences risk perception	Violent and deliberate plundering of a site with the purpose of acquiring valuable objects	Small to minimal effect as the driving motive dominates possible precautionary measures, pre-programmes destruction of the marking
2	Adversity	Alleviating materially intolerable living conditions (poverty in "3 rd world countries", example "theft of medical radioactive sources")	Minimal, negligible in the adversity situation	Violent plundering of a site with the purpose of acquiring valuable objects to improve existential hardship	Small to minimal effect as hardship is considered more threatening than the risk from the repository; destruction of near-surface marking likely
3	Curiosity	Satisfying the drive by fulfilling the need: appropriation of knowledge for individual use (researchers; example "archaeology")	Average to high, depending on what individual preferences dominate	Deliberate intrusion into the underground environment and the repository possible	Relatively large effect of marking, particularly underground
4	Profit maximization	Retrieval of emplaced, economically potentially lucrative materials such as waste (treasure-seekers, example "recovery of gold and silver and everyday objects from sunken ships")	Small to large, depending on whether processes are coupled	Deliberate intrusion into the repository, cost of intrusion determines the economic success of the undertaking	Relatively large effect of marking, particularly for underground structures
5	Sense of responsibility	Averting danger from a leaking repository (clean-up programme, examples "decommissioning of hazardous waste disposal sites in Switzerland")	High, knowledge of danger potential good	Deliberate intrusion into the repository, costs of intrusion relative to health risk	Large effect of marking, particularly for underground structures and disposal tunnels
6	Herostratism, wilfulness, fanaticism	Satisfying the drive by fulfilling the need: appropriation of hazardous material for destructive purposes and for harming others (e.g. terrorism)	High because the source of danger is deliberately being sought to use it for destructive ends	Deliberate and presumably fast and violent intrusion with the purpose of acquiring hazardous material	Large effect of marking, particularly for underground structures and disposal tunnels

Table 4.1a: Overview of potential risk scenarios for intrusion into a radioactive waste repository and protection factors of marking programmes

	Risk type	Driving force for action or reasons for non-action	Risk perception	Form of realisation	Protection factor (effect) of a marking programme on intrusion
7	Lack of interest	Absolute indifference to source of danger, complete blanking out of danger	Minimal, risk is not recognised or, at best, played down	Risk of intrusion only in the case of exploration of underground environment	Marking presumably has only a restricted effect
8	Negligence	Indifference to source of danger, complete blanking out of danger	Minimal, risk is not correctly perceived	Risk of intrusion only in the case of exploration of underground environment	Marking presumably has only a restricted effect
9	Ignorance	Loss of knowledge of a potential danger and of the know-how and possibilities for recognising the danger: exploration and use of the underground environment possible	No risk perception because source of danger is not known	Risk of intrusion in the case of exploration of underground environment	Marking presumably has only a restricted effect
10	Coupled processes (e.g. ignorance and curiosity)	Realignment of interests and assessment of danger possible	Minimal to large depending on the scenario	Risk of intrusion in the case of exploration of underground environment	Effect of marking varies

Table 4.1b: Overview of potential risk scenarios for intrusion into a radioactive waste repository and protection factors of marking programmes

- Ignorance: Ignorance assumes completely forgetting something and can be seen as a cumulative social process of disinterest. Most of the intrusion scenarios discussed in the literature assume a complete loss of knowledge of the presence of the repository.
- Coupled processes: Many of the motives discussed above can be coupled. It is entirely conceivable that, for intrusion scenarios, curiosity will also play a role and that, in one form or another, complete or partial emptying of the repository with subsequent use could occur.

The driving forces and the effects of human behaviour therefore differ widely and this should be considered carefully when marking programmes are discussed.

4.2 Fundamental questions on the intentions and objectives of marking

01 Why should marking be done? What reasons can be given for justifying or rejecting marking?

Problem definition

The concentration, alteration and use of radioactive materials leave behind waste that presents a serious risk for living beings for very long time periods (Buser 2013). As a rule, responsible authorities and implementing organisations assume times of up to 1 million years for which this waste has to be excluded from the human environment (Milnes et al. 1980 [page 359]; Nagra 2008a [pages 14-16]; Nagra 2008b [page 27]; AKEnd 2002, HSK 2005 [pages 33, 45, 237], ENSI G-03) (see also section 04). Such timescales are inconceivably long from a human perspective and represent a new challenge for the societies confronted with them. In this sense, they have a new significance in the context of how man confronts his future.

As the radioactivity of the waste can be controlled only to a restricted extent and long-term effects are at best only influenced by transmutation, repositories in stable deep rock formations today represent the generally recognised strategy for dealing with a problem that has become more acute in the last decades (EKRA 2000). The measures for protecting the environment from radioactive substances are basically of a technical nature, but corresponding requirements have also been formulated for the marking of a repository. For Switzerland, marking requirements are defined by EKRA (2000, 2002) and prescribed by the Nuclear Energy Act (Art. 40, par. 7) and the Nuclear Energy Ordinance (Art. 69, par. 3). The objectives of marking are not, however, justified.

Information in the literature

There seems to be a general agreement in the literature that the main function of marking is to warn future generations (Cameron 1981, p. 184; Posner 1990a; Ohuchi et al. 2003, p. 1227; Sugiyama et al. 2003, p. 1). Another objective is to provide information to future generations that will simplify their decision-making processes (Ohuchi et al. 2003, p. 1227; Sugiyama et al. 2003, p. 1). However, these objectives are not completely unchallenged. For some time, doubts have been expressed about them and the question has been raised whether collective “forgetting” of the repository location would not be better. Pescatore et al. (2007, p. 1) and the NEA (2007a, 2008) have gone down a different road by suggesting that the repository should be considered as part of a social “factory” which, aside from the objectives already mentioned, passes on the memory of the repository from generation to generation. This concept converges to some extent with the old ideas of the guardianship concept (Macy 1992) or the involvement of stakeholders (Tannenbaum 1984, p. 13), as far as the role of cultural knowledge transfer is concerned.

The debate on the long-term benefits or disadvantages of marking is still ongoing. The question is: Would forgetting a repository not ultimately reduce the potential risk for future generations?

Appraisal

However the question is phrased, it will be difficult for clear answers to endure, since the means of assuring safety in an uncertain future are strongly value- and position-dependent and hence inherently unpredictable. On the other hand, it is worthwhile to look more closely at some detailed aspects of marking as they can support or undermine the justifications for the overall objective. Individual aspects are considered from a wider viewpoint in sections A5, B4, C2 and E2. It may become clear that this overarching question will be obsolete because, with a certain level of knowledge being maintained, a repository cannot be excluded from collective memory.

Initially it seems obvious that, out of concern for the safety of future generations, countries using nuclear energy will assume a responsibility to place visible or recognisable marking of repositories at the earth's surface. From this perspective, marking in the sense of a warning to future generations is clearly affirmed.

In view of the marked dependence on social values and the deep-seated change that these generally undergo as part of historical processes, the question is whether what makes sense today will make sense tomorrow. As with all societal systems, change is either difficult or impossible to predict unless we are talking about the general lines according to which societies orient themselves. It is doubtful whether better methods will ever exist for predicting changes of this nature over long time spans. For this reason, there is resistance on the part of some researchers to make marking the panacea against intrusion into a repository by future generations. It cannot really be expected that these contradictory positions will be resolved. The pros and cons of marking will always be a matter of discretion.

02 Under what conditions is it possible to warn future generations?

Problem definition

This question is systematic in nature. It asks under what conditions the encoding of messages, knowledge transfer and decoding of information have to take place to ensure that there is no (significant) distortion of the information content. This raises a whole series of additional questions, such as the technologies used for encoding and decoding, the general question of loss of information, historically evidenced mechanisms of information loss and the willingness and ability of future generations to act. The requirements that have to be met to ensure that information is transmitted factually and correctly are enormous. All future historical disruptions with partial loss of knowledge or the control over this knowledge have to be bridged. This assumes that future generations will always find their way back to political and social systems that are based on reason. If such development breaks down, transfer of information over time can no longer be predicted.

Information in the literature

This question contains a whole series of problems of a semiotic, language history and socio-political nature. Encoding and decoding of messages are technologies that use defined guidelines (algorithms) with a high degree of abstraction and complex encoding properties (Pierce, Verón 2004). The evolution and change of language effectively cannot be controlled and – in retrospect – present huge challenges for the decoders if information has been lost. Without wishing to detract from the brilliant achievements of individual researchers, success in decoding ancient or lost languages depends to a significant extent on the existence of language bridges that allow lost knowledge to be reconstructed (Doblhofer 1993). Without such bridges, the decoding of lost written languages is virtually impossible, even with the computer-based analysis technologies that are available today (see also E3). Developments in technologies and social structures also raise questions. As Kowalski (2002) has shown for the example of technology development, predicting change and the direction and rate of change is at best only partially possible. This is even truer for political processes which follow no logic in their evolution and hence make prediction of events superfluous.

The literature deals mainly with individual questions (see A5, B2). At least as far as the present evaluation is concerned, the overarching question of what requirements have to be met to ensure communication over long timescales was addressed from early on (Hauser 1990a, p. 187 ff.), but has not been dealt with systematically. Interesting methodological approaches for treating such questions include fault tree analyses (as developed for scenarios of intrusion into a repository, see Trauth et al. 1993, Appendix A Human Intrusion Scenarios); these divide a risk process systematically into logical chains of action to allow the vulnerabilities of the different sub-systems to be determined.

Appraisal

As for the question of the reasons for marking (see 01), the question of what requirements have to be met for informing future generations of the presence of the repository using marking cannot be answered conclusively today. If this extremely complex question is to be properly addressed, it will be necessary to consider all possible requirements that have to be developed and implemented to ensure communication over long time periods. There is currently no methodical means available to allow this question to be answered. Fault tree analyses could, however, be used to identify the vulnerabilities and weak points of the individual sub-systems.

Such an approach would be interesting as it would allow the entire process of information transfer over time to be run through intellectually. This complex undertaking could highlight significant hurdles or weak points in the process.

03 Is marking feasible at reasonable cost?

Problem definition

This question is not about the technical feasibility, but rather the political or economic feasibility of implementing a marking concept. Some of the questions that arise in this regard are: Have economic factors been considered? Is a society even interested in the long term in implementing a marking concept or continuing and maintaining marking measures? Is atomic “monument conservation” possible or even desirable? Does a marking project also imply the creation of structures that become autonomous, in which case control could slip away from society as a whole (Garfield 1994)? The questions are highly complex, but the aim should be to provide factually based answers to the fundamental question.

Information in the literature

As was the case for previous questions, some aspects of the fundamental issue have been considered fairly extensively in the literature. There continues to be considerable interest and relatively strong disagreement over the question of an “atomic priesthood” (Sebeok 1990, p. 141 ff.; Weinberg 1972; Weinberg 1999; Blonsky 1990, p. 181 ff.; Hauser 1990b, p. 195 ff.; Garfield 1994). The starting-point for this discussion was in 1971 and arose from differences of opinion between nuclear experts during the course of an IAEA meeting (IAEA 1971, p. 467 ff.). In the following year, this led Weinberg to publish his viewpoint in an article in the journal “Science” (Weinberg 1972). He refers in his article to the “Faustian Pact” sealed by the nuclear community that made immeasurable energy sources available but called for social institutions to be vigilant and long-lived. Weinberg later used the term “scientific millenarianism” (Weinberg 1999, p. 531, 537 ff.), which has its roots in the Second Coming of Christ and his thousand year reign and the credo of apocalyptic religious movements in the Middle Ages (see e.g. Cohn 1961; Minois 2002). Scientific millenarianism adopts the belief of the absolute predetermination of events that belongs to Chiliasm³. The question of institutional control in the future is only one of the core questions in this context.

Economic aspects have stirred up much less dust, even if they can have equally serious consequences such as structural deficits. The literature on topics such as the cost of waste disposal,

³ Chiliasm: Radical Christian doctrine stating that Jesus will reign on Earth for 1000 years, see Glossary.

cost-risk analyses or economic efficiency is wide (WIPP 2000; Neill et al. 2003; WIPP 2004a). These studies mostly settle for making the point that economic predictions only reflect trends (NEA 2006, p. 14).

Experience has shown that larger-scale projects are more economically efficient, which undoubtedly speaks in favour of international disposal projects, as presented, for example, by Chapman et al. (2003) and McCombie et al. (2002, p. 6 ff.). The call for atomic monument conservation is ruinous from an economic perspective and would seriously call nuclear energy production into question (Schüring 1995, p. 174). If individual cost positions of atomic monument conservation were to be extrapolated over 10,000 years, such an undertaking would not be economically feasible⁴.

Appraisal

As for the previous question, there is no comprehensive method available for reliably determining the cost of marking. Rough assessments of the financial commitment under very simplified assumptions lead to the recognition that tasks of this type are almost impossible to assess from a financial perspective and cannot effectively be covered by the generations enjoying the benefits. Even more uncertain is assuring the structure of a marking programme, meaning that, beyond general principles, very little can actually be said about future organisational forms for monument conservation. However, the question remains politically explosive, particularly with respect to the ethical components of the actions of the current society.

04 How far should we go in protecting future generations?

Problem definition

The question deals with ethical principles, particularly when safety requirements can be considered as being fulfilled from the viewpoint of the benefitting generations. The question is closely associated with the principle of sustainability, which is accepted today as the basis for social actions.

The question of how far the protection of future generations should go sets a yardstick for determining how much has to be done today to fulfill the principle of sustainability, and not only from the viewpoint of radiological protection. Hand in hand with this there is also a moral issue or requirement associated with responsible action that should bring an ethical exoneration of the generation which has benefitted from the use of nuclear power (the 'benefitting generation'). How far should we go with the disposal of radioactive waste – and specifically with marking – to fulfill the "duty" arising from the use of nuclear technology for the future?

Answering such a question will of course have a multidimensional aspect, as both "safety" and "duty" reflect value sets that are dependent on culture and time and will thus be subject to significant change. "Safe" for the proponents of the disposal technology means a geologically safe disposal system, while opponents speak of safety when production of radioactive waste has ceased. A marking system can range from practically nothing to a contrived and monumental multi-component system that will have to be maintained in the future. What is important in this respect is not only what has to be done to ensure sustainability, but also how this can be justified philosophically or ethically.

Information in the literature

Questions of this nature have been addressed primarily by international organisations such as the IAEA and the OECD/NEA. Attempts have been made since the 1980s to define the requirements relating to sustainability of deep geological repositories (see e.g. Linsley et al. 1989; IAEA 2006; NEA

⁴ Depending on the waste disposal facility and its condition, monitoring and maintenance will cost several tens of thousands to millions of Swiss Francs per year, which, extrapolated, would mean millions in financial reserves for atomic monument conservation. Interest models that give a more or less constant return over long time periods (>several decades) are inconceivable, as evidenced once more by the current financial crisis (see contributions on the history of speculation, particularly Galbraith J.K. [1992]).

2007); this has raised a broad spectrum of technical and scientific requirements. The criteria are considered to be “met” and a repository to be sustainable when it can be implemented in such a way that the protection of humans and the environment is assured over the foreseen containment time on the basis of passive safety measures alone (see Pescatore et al. 2007, p. 2; Blonsky 1990, p. 171).

The realisation of a repository for which safety relies on passive systems has to be supplemented by additional measures ranging from relatively conventional measures for transferring information (e.g. maintained and durable archives and contrived marking technologies; see e.g. WIPP 2000, WIPP 2004a, WIPP 2004b) to novel proposals for cultural trading that go far beyond purely linguistic or ethnologically driven information transfer (Pescatore et al. 2007, NEA 2007a).

These trading issues aside, technical safety is a sine qua non. Lessons should be learned from negative experience and planning mishaps with conventional waste disposal facilities (legacy wastes), which highlight an entire spectrum of poor decision-making in the past. In the first instance, this means more planning reliability and increased planning quality and the involvement of the responsible authorities and siting regions in planning decisions (Pescatore et al. 2007, p. 5, NEA 2007a, p. 35 ff.), reducing the susceptibility of technical systems to errors, introducing predetermined breaking points, etc. These technical improvements should not be developed within closed expert bodies, but have to be evaluated and accepted by the affected stakeholders. Probabilistic safety analyses alone will not satisfy this requirement.

Appraisal

The role of the benefitting generation is clearly traceable in the literature. They are expected to develop and implement a passively safe deep disposal system that remains functional for as long as the radioactive waste presents a hazard. However, the means that should be used to achieve this, and who should be involved, are unclear or even disputed. As concrete plans for repositories show today, there is still a long way to go in drawing lessons from past planning mistakes with legacy wastes.

There is no consensus today on the extent to which future generations should be protected. Most scientists who have expressed themselves on this in the technical literature consider the protection of future generations to be fulfilled when repositories can be operated safely in accordance with models and predictions. However, as soon as societal aspects enter the equation, the issue becomes complex. To name only one example – how should the issue of raw materials and conflicts of use be handled when these involve future generations? For future generations, every direct dealing with the waste left by their predecessors becomes a burden.

05 What should be handed over to future generations?

Problem definition

The question relates in the first instance to the content of the information passed on to future generations. What information should be transferred? Should it relate to the hazardous system as such (the repository and its properties) or should it include additional information such as, for example, the context in which the repository was realised? Should an entire marking system be passed on - in concrete terms a definitive and robust information system - or is the intention that future generations should help to shape the information? How should decisions be made on what and what not to communicate?

Even if it gives a first impression of being somewhat banal, the question itself is anything but trivial. As in the literature for sections D1-D4 and E1-E4, we can find a wealth of concrete ideas and technologies for marking a repository, the materials to be used and their expected lifetime, semantic

issues, encoding and decoding questions, etc. The obvious question of what should actually be communicated is less well addressed.

Information in the literature

As the background and literature of any waste management programme show, there is an endless number of documents on topics ranging from research applications and projects (research plans, sketches, applications, experiments, etc.) through daily handling of business (budget planning, financial control, annual reports, letters, protocols, e-mails, etc.), information media (photos, films, flyers, information brochures, press articles, etc.) to scientific reports (documentation of meetings, internal and external reports) and characterisation of waste (datasets for wastes and packages for disposal, codes, etc.). Syntheses of entire projects are rare, as are the systematic treatment of site data, systematically maintained files of plans and site-specific investigation data, accidents and perturbations, trading technologies and so on that would provide information to future generations on the content and risks of the emplaced waste and the configuration of the facility. This problem is well known for the case of waste disposal facilities and is the reason why clean-up and remediation are generally so costly and only a fraction of the important information can be obtained. When trading information, it has to be assured that not every dataset or document with non-essential information is transferred, as future generations would presumably have real problems with evaluating the large volumes of information and the different data transfer media (Cohen 2005). The real issue is: what do we transfer to the future, and in what form, to ensure that our descendants receive meaningful and understandable information. As a result of these deliberations, a number of information levels can be distinguished (see C3).

As previously mentioned, these aspects have received only limited attention in the literature considered. There is any amount of information on what is possible, and how and where, but no systematic analysis of what information should actually be passed on. Some authors (Kaplan 1982, p. 74; HITF 1984, p. 43–52; Tannenbaum 1990, p. 133 ff.) draw a distinction between different levels of information that should be transferred to future generations (see C3); they also raise questions regarding the understandability of information over time, but do not go on to address what information should be transmitted and in what form. Even Sprenger (2007, p. 28 ff.) does not directly consider the actual information content to be transferred. WIPP (2004a, p. 7), on the other hand, explains that “sufficient” information should be transferred, but does not specify what this is⁵. WIPP (2000, p. 49 ff.) also presents an impressive test programme for checking the durability of information media for marking systems. The traceability of such data, in line with quality assurance programmes (WIPP 2000, p. 45), is mentioned in such projects, but is not projected back onto the information objects. The question is whether such quality assurance rules will make any sense in 10,000 years as retracing the processes will no longer be possible.

Appraisal

The fundamental question regarding the type and amount of information to be transferred has not been adequately addressed to date. Rectifying this would be important for any marking programme.

06 Are the potential for misinterpretation and manipulation, and/or the susceptibility of the marking system to errors and perturbation, recognised as important elements?

Problem definition

The question here is essentially about the potential changes in the marking system over the course of time. Very diverse effects and consequences have to be considered. Transformations in the

⁵ “To inform an intruder about the degree and nature of the danger, permanent markers must [...] contain sufficient information about the site and its dangers to dissuade intrusion and should be identifiable within the first four levels of understanding (as discussed in the CCA, Appendix PIC).”

information content can accompany the marking system as a type of “noise” and falsify it in many different ways. This can also be caused by natural processes at the earth’s surface such as erosion, frost damage, vegetation growth etc. This susceptibility to perturbations and errors may occur not only due to systemic changes but can also be introduced deliberately. In the latter case, the quality of the transformation is different, namely deliberate manipulation or destruction of a system by future generations or cultures.

Information in the literature

Some aspects, such as the transformation of information in the sense of a change in language or encoding or decoding problems, have been known for some time, mainly by semioticians (Sebeok 1984; Tannenbaum 1984). This is not surprising because semiotics deals fundamentally with transformation processes of information and investigates these systematically. This brings to light different sources of perturbation or distortion that should be considered and that can fundamentally change the meaning and content of information. The semiosis model (after Pierce, cf. Sebeok 1984; Verón 2004 and Figure 4.1a) considers not only the process of transformation of a specific message, but also the processes resulting from contextual social changes or changes that are dependent on external factors. Examples include cultural changes and ruptures (Imhof et al. 1989) that lead to partial or complete loss of cultural identity attributes such as language, myths, values, customs and other trading systems. Such thoughts were also formulated in the context of hermeneutics or the deconstruction theory and were raised in a more general sense by constructivists (e.g. social constructivism, see Berger 1966; radical constructivism see Watzlawick 1976). Perception, reality and distortion are always in the foreground, with the manifold possibilities for influencing these, either consciously or unconsciously (Figure 4.1).

Another important aspect is that of deliberate manipulation, influencing or destruction of information. Much can be learned here from archaeological and historical processes, particularly the deliberate destruction of the cultural identity of conquered peoples (Kiernan 2007), starting from the Bible and the occupation of the “Holy Land”, the eradication of Moab from Canaan and the occupation of the West Jordan valley by the Israelites (Bible, Numbers 50-56, Joshua 6,20-21; 8, 24-29, etc.) to the widespread atrocities of the 20th century with fully-fledged extermination campaigns (Armenia from 1915 [Balakian 2003]; Germany under Hitler [Bloxham 2003]; the Soviet Union under Stalin [Courtois 1998]; China under Mao [Halliday et al. 2005]; Cambodia under Pol Pot [Chandler 2007], etc.). That these waves of obliteration are apparently part of human make-up is evidenced by the slaughters that have already taken place in the new millennium (Darfur in West Sudan, Eastern Congo, etc.). From ancient to modern times, conquering cultures have attempted, in the course of such slaughter, to wipe out the cultural heritage of the vanquished people, to say nothing of the fear that genocide is part of man’s fundamental make-up (Leakey 1999, p. 133). A recent example of the destruction of a cultural heritage driven by motives of religious fundamentalism occurred in March 2001 in multicultural Bamiyan in Afghanistan: the blowing up of two Buddha statues that were some 1500 years old⁶.

Appraisal

For radioactive waste, both transformation and manipulation have been considered, in the first instance in the field of semiotics (Sebeok 1990, HITF 1984), but also by international agencies (NEA 2002). An in-depth analysis of the manipulation and destruction of information and the consequences for a geological repository could not be found in the literature considered. Trans- or interdisciplinary treatment of this diverse problem would be helpful at the current stage of planning the basic designs for disposal concepts, selection of the canister materials to be emplaced and the definition of marking. Archaeological and cultural anthropology studies could provide valuable information, particularly in connection with cultural disruption. The universality of such phenomena (Grinsell 1975) should be sufficient reason to assign highest priority to this issue.

⁶ <http://www.pf.igp.ethz.ch/research/bamiyan/buddha/destruction.html> (and in early 2013 the same attempt in Mali, archives of Timbuktu)

Figure 4.1a: Semiosis after Sebeok (1990)

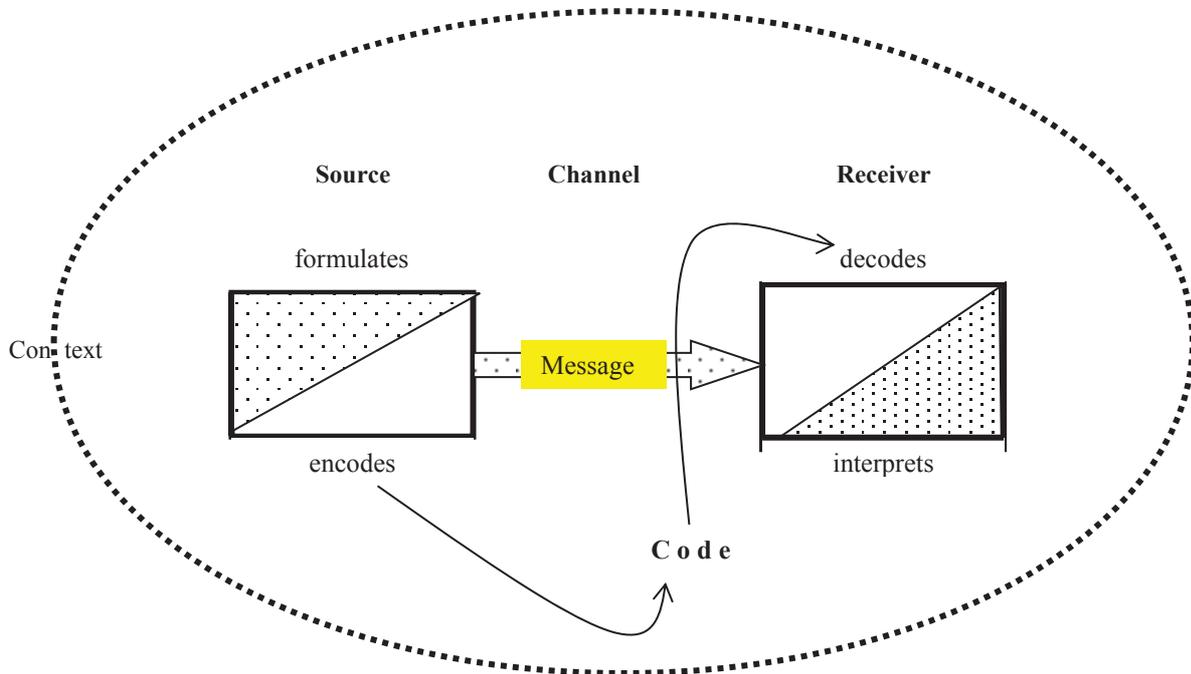


Figure 4.1b: Semiosis for long-running messages

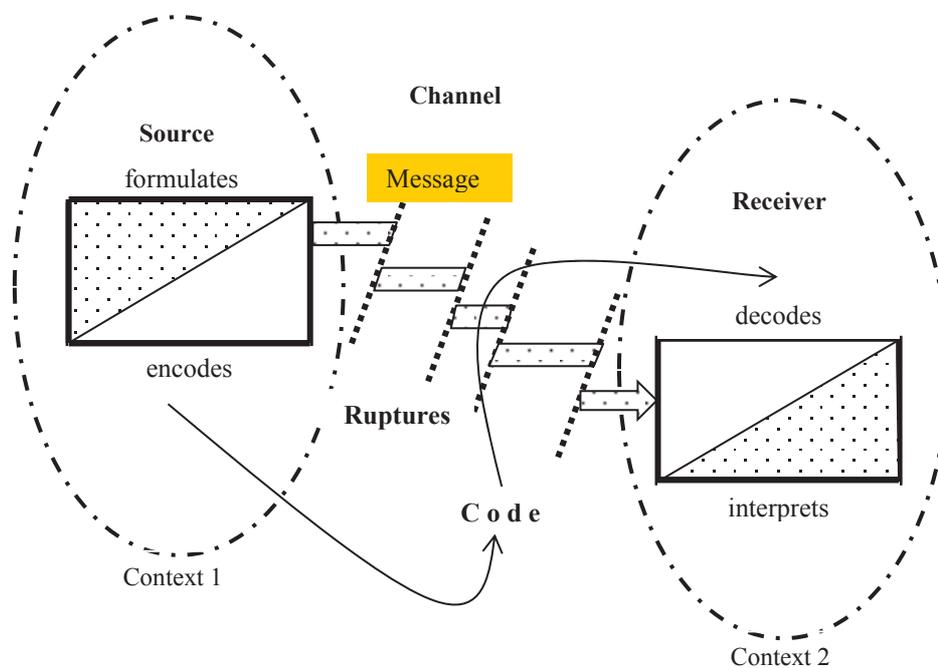


Figure 4.1: Semiosis after Sebeok (1990) und Semiosis for long-running messages

4.3 Questions on the specific sub-systems

A Humans and society

A1 Who is marking directed at in the future (“primitive” society or advanced civilisation? Are evolutionary aspects addressed in the marking literature? Can processes and changes of this nature even be recognised (e.g. scenario analyses)?

Problem definition

To whom should the warning about the repository be directed? This is one of the fundamental questions that arise when safety is being considered over timescales of 1 million years, at the same time looking back at the development of hominids over a similar time period (see Figure 2.2). Looking into the past shows that modern man has a “career” (Schneider 2008) of around 100,000 years behind him and the question can rightly be asked as to what form of – possibly more highly developed – beings we will be leaving our waste to. This cannot be answered, but is nevertheless of considerable ethical relevance when sustainability is considered as a guiding principle for modern societal activities.

Information in the literature

Several authors have recognised this problem in principle but have interpreted it in different ways. The discussion of the origin and future of *Homo sapiens* is an ongoing issue in the history of human awareness, but was given a completely new significance with Darwin’s “Origin of the Species”. The late 19th and first decades of the 20th century are full of the subject (Boia 1989), from literary treatments (e.g. Bulwer-Lytton’s futuristic novel “The Coming Race” or Maupassant’s “Horla”) to numerous programmes on socio-biological and eugenic human processing (Wess 1989). In the last decade, anthropological and neurobiological research has focused increasingly on these topics. More information can be derived from evolutionary treatises of language (Berger 2008, Watson 2005), which show that evolutionary processes in a hominid species occur stepwise and that there is feedback between biological-neurological and intellectual-technical capabilities.

In the context of nuclear waste management, the question of the direction in which society could evolve was already the subject of controversy at the beginning of the 1970s (IAEA 1972). Marking studies at the beginning of the 1980s again tackled the question. Tannenbaum (1984, p. 4 ff.; 1990, p. 127 ff.) analyses possible evolution scenarios and stresses the significance of information transfer in the event of changes in species and technology. He points to the enormous rate of expansion of human perception that has been evident in technical processes in just the last 100 years (see also Buser 1998, p. 51). Like Kowalski (2002) for technology impact assessment, he concludes that evolutionary processes cannot be answered. Socio-biological and genetic changes in the technical make-up of modern man can also play a role, meaning that present-day *Homo sapiens* could be strongly affected by genetic-medical intrusions into his DNA on the medium term.

Other authors assume that changes in human evolution could be less marked. Bastide et al. (1990, p. 92) believe that human morphology and modes of expression will change little in the next 10,000 years as they have already existed for significantly longer. Givens (1990, p. 96) puts forward similar arguments, assuming an isomorphic evolution for the species *Homo sapiens* and language and information trading to be a more or less uniform process. He therefore believes that a warning system should be developed for present-day *Homo sapiens* and not for some unknown species.

There is consensus in the literature that predicting the actual evolution of species and society is not possible and can only be treated to a limited extent. As scenarios, they can however provide valuable indications of how information transfer could be foreseen for different evolution conditions (Benford et al. 1991, p. 5; see also B2).

Appraisal

The question regarding the recipients of a message or a warning about a repository was undoubtedly identified at an early stage, but seems to be of only limited interest as it does not involve any additional input for instructions on how to act. Systematic analysis of scenarios could, however, provide important information on how to design information depending on to whom it is addressed to in the future (i.e. primitive versus advanced civilisation).

A2 How long should marking last? In other words: for what time periods should a marking system be conceived? Should different marking technologies be used for different risk situations?

Problem definition

The question of the duration of marking depends to a large extent on what actually has to be marked and what has to be considered - only the surface, specific facility components or more or less the whole facility (i.e. the geological repository, access routes and the overlying protection zone). As long as the repository and the accesses (shafts) are not exposed by natural events or damaged or put out of operation by human intrusion, the question of the duration of marking is not particularly relevant or is even obsolete. The situation is different for objects or facilities at or near the surface or for documents that require to be archived. These are directly exposed to social processes and environmental forces. Questions of the duration of marking are very important in the latter case.

Information in the literature

For geological repositories, two completely different time periods are considered in the literature. The information on the first time period is based on considerations of waste quality and the decrease in radiotoxicity with time. In line with other national programmes, the Swiss waste management programme assumes isolation periods between 100,000 years (L/ILW repository) and 1 million years (HLW repository) (Nagra 2008b, p. 27), with radiotoxicity decreasing significantly in the first 1000 years. The time period considered for marking in most studies is 10,000 years (Benford et al. 1991).

This period of 10,000 years is justified in different ways: Blonsky (1990, p. 171) notes that it corresponds to the half-life of radioactive waste from weapons' programmes. HITF (1984, p. 11) presents a similar argument. Givens (1990, p. 95) believes that messages that have lasted for thousands of years were not actually intended for future generations and justifies the 10,000 time period in this way. Kaplan (1982, p. 1) argues that the time period is consistent with the criteria applied by the EPA⁷ for the management of waste. Tannenbaum (1984, p. 1) notes that the time period of 10,000 years is reasonable for the neutralisation of radioactivity. Sebeok (1990, p. 141 ff.) states that the 10,000 year period is arbitrary. It is clear that the "hard" scientific time stamps and the time periods considered by society to be acceptable for communicating with the future cannot be reconciled. In terms of transmission of information, communicating over 300 generations (around 10,000 years) is already a very special challenge and can be guaranteed possibly only via special relay functions (Sebeok 1984, p. 2).

The requirements relating to the durability of communication over long time periods can be used to derive requirements on potential transmission technologies on the one hand and site-specific boundary conditions on the other (HITF 1984). The transmission technologies call for a high degree of redundancy, allowing information to endure via numerous different channels and with different technologies, materials and configurations. For the site-specific boundary conditions, the characteristics of the environment are decisive in terms of climate and scenarios of population and land use (see HITF 1984, p. 31 ff.). The consequences for marking technologies and their durability over time (see B1, E2) were highlighted at an early stage from the viewpoint of archaeology and material technology (Kaplan 1982, Berry 1983).

⁷ US Environmental Protection Agency.

For underground structures, marking is meaningful because of the requirement for retrievability. However, this issue is not critical in terms of the problem of the durability of the marking materials.

Appraisal

10,000 years is a long time and cannot really be justified in terms of social maintenance or support. It corresponds to the historical time horizon that produced the Neolithic Change, arable farming, animal husbandry and stockpiling. In many cultures, this lies between several thousand years and more than 10,000 years in the past. Going further forward and considering an even longer marking period does not make sense, even if it is technically possible to manufacture marking materials with a much longer lifetime (see A3, C3 and E2).

A3 What role do technology and technology development play in the question of marking?

Problem definition

The question of the applicability and material durability of the information media used leads directly into the question of technology and technology development. The question is whether technological development is predictable and what risks have to be considered in association with the rapid progress of deep disposal technology. Finally, there is also the question of whether technology alone is sufficient to assure adequate protection of a deep repository.

Information in the literature

With the rapid development of technology and the foreseeable expansion of the use of the deep underground environment by humans⁸, the most urgent safety-related problem is the long-term protection of a repository from prospecting and large projects in the underground environment (e.g. geothermal, Swissmetro). Technology is developing so rapidly that optimised or new, less costly methods for accessing the underground are already a reality (see Häring 2007; methods such as e.g. fusion [heat] drilling with flame or plasma arc technology, steam jet fusion drilling with high-temperature steam). With these potential risks to a repository, marking will become more important in the future.

In geometric terms, marking above the perimeter of a deep repository no longer offers sufficient protection from intrusion using horizontal drilling technology (see Benford 1991, p. 20; Häring 2007, p. 37) and certainly not from tunnel construction. If use of the underground space continues at the same rate as in the last 100 years - which can be assumed at this point - marking strategies against lateral penetration into the repository will have to be designed (see C2).

In the literature, there is a wealth of evidence that, already in historical times, "simple" technologies made it possible to penetrate deep into the earth. As part of a historical treatise on drilling technology, Buja (2003, p. 654) notes that China had drilled boreholes several hundred metres deep in 600 years BCE. Since the drilling of the oil borehole in Spindletop (Beaumont, Texas), which marked the beginning of modern oil-well technology, the rotary drilling technique for boreholes up to several hundred metres can be considered as tried and tested. The same applies for mining and tunnelling technology. Accessing of deep mines goes back to ancient times and is well evidenced in several areas (e.g. the ore-rich island Thasos; for literature see Kleiner Pauly 1975). In the Middle Ages, the mining of salt, coal and ore in Europe from depths of hundreds of metres became more common (Agricola 1557/1928). The steam engine helped modern mining technology to finally make a breakthrough. By the 19th century, many locations worldwide had mines at depths greater than 1000 m; since the 20th century, depths of more than 3500 m have become common (Western Deep Mine, South Africa). The same applies for accessing the underground using railway tunnels, which became

⁸ Western Deep Mine will reach a depth of 5 km in the coming years; boreholes to depths of 10 km have been state of the art for decades (Kola, Russia: 12,262 m; Sakhalin Russia: 11,680 m; Bertha Rodgers Oklahoma: 9583 m).

a success story from the 19th century (e.g. Gotthard tunnel). These examples show how important it is to design marking systems aimed at preventing penetration into the facility itself.

Appraisal

Marking technologies and the characteristics of the materials used, and the processes that can lead to degradation of these materials, have been dealt with extensively in the literature (see B1, B3, C2). For marking near the surface, strategies and industrial marking technologies are so well developed that they can realistically be implemented in actual projects. For marking the repository itself and its accesses, however, many questions remain open, particularly in the case of a threat coming from the side. Marking the repository with strong magnets or other corrosive materials (see C2) is questionable given the potential for gas formation due to corrosion and the ensuing damage to functionality. Added to this is the fact that success in transferring information using semiotic techniques also remains open due to the uncertainty associated with cultural and social evolution (see D3).

Marking systems underground can, without doubt, be improved by developments in technology. However, current understanding indicates that technology plays a secondary role in this respect. It remains open what protection and marking measures are possible against lateral intrusion and how they could be configured.

A4 Who should implement marking? What structures are important for long-term safety management? What structures/organisational measures could be essential after closure of the facility (e.g. legal title, responsibilities)?

Problem definition

The question relating to the structures for long-term safety management has two fundamental aspects: the role of state organisations in the waste management programme and who takes over responsibility when a repository is closed. Both aspects are essential to the issue of marking.

Information in the literature

In the context of defining fundamental principles for nuclear waste management, the IAEA (1995, paragraph 323) notes that long-term responsibility and continuity of responsibility have to be regulated. The IAEA (1999, p. 12) raises the question of the institutional control of repositories and answers it to the effect that the state should identify and appoint the organisations responsible for institutional control of a repository (e.g. state department, agency or another organisation designated by the state). The definitions of the US Environmental Protection Agency (US EPA 1993) are along the same line. Chapman et al. (2003, p. 149) discuss the significance of regulations relating to use of land and resources resulting from American legislation. Sugiyama et al. (2003, p. 2) also refer to the advantages of involving the state or special bodies in institutional control of the site of a repository.

The question as to who should actually implement marking depends to a large extent on the structures set up by a country to deal with the waste management issue. The polluter pays principle, as embodied in the Swiss Nuclear Energy Act, is not applied in this sense in other countries. The majority of countries with nuclear energy programmes, such as France, Spain, Germany, Belgium and the USA have entrusted the management of radioactive waste to state organisations. The electricity producers have therefore handed over responsibility for planning and implementing repositories to state-run bodies. In contrast, Switzerland also applies the polluter pays principle to radioactive waste.

Electricity utilities – in the first instance the power plant operators – are thus responsible in Switzerland for the planning and implementation of repositories. Questions have been raised in this regard as to whether an organisation effectively oriented to profitability will really consider all aspects of long-term safety (Buser et al. 1981, p. 175).

Appraisal

Strong involvement of democratically legitimated public institutions in long-term control is already clear in different national and international regulations, but has not yet led to any definition of generally acceptable marking strategies. In Swiss law, these questions are regulated to some extent in Article 70 of the Nuclear Energy Ordinance, particularly regarding legal title to private property in the protected zone of a repository.

The involvement of the public hand in the long-term control of repositories results in Switzerland from the fact that, after closure, the owner of a repository no longer exists as a legal person. All issues relating to protection of the repository therefore become the responsibility of a public institution. In Switzerland, these provisions can be found in the Nuclear Energy Act (Art. 39 and 40) and associated Ordinance (Art. 69 and 70).

A5 What motives for intentional/unintentional exposure (exhumation) of the waste have to be considered?

Problem definition

The problem here is understanding what could lead future generations to exhume a repository, either intentionally or unintentionally. Archaeologists theorise about the motives for exhuming graves (Grinsell 1975), and also about the motives underlying such action (Grinsell 1975, p. 101 ff.). The list of motives appears not to have changed with time: adversity, the search for resources, greed, desecration of burial sites, vandalism, herostratism and curiosity have long been recognised as driving forces (see section 4.1). The question of the motive for intrusion is important not only for planning the repository but also for the marking strategy.

Information in the literature

The literature on grave robbery is almost endless and, in this sense, reflects the universality of the phenomenon throughout all cultures and times. In the sense of an updated perception, which assumes that current processes and actions were also valid in the past, it can be assumed that exhumation of repositories will also be a reality in the future. The motives for this will follow the same stimuli, but will differ greatly from one another.

The term exhumation, originally used to refer to opening graves and removing corpses, was introduced with new connotations in connection with the intentional removal (retrieval) of near-surface radioactive legacy wastes, particularly in the USA since 1970 (Noyes 1995). In this sense, the term anticipates the retrieval of radioactive waste from deep repositories; this has been the subject of investigation for old L/ILW repositories such as Asse and Morsleben (Hartmann et al. 2008; www.bfs.de/de/bfs/wir/Aktenplan.pdf) or is considered in the context of new repositories (Nagra 1998, Nagra 2002a). From a technical viewpoint, the equipment and experience needed to recover waste from deep repositories exist today (Nagra 1999a; see also removal during clean-up of old special waste dumps); in such cases, safety and economic considerations can be limiting. A scenario not described in the literature to date is the deliberate retrieval of waste for spatial planning reasons (e.g. very densely populated areas with high heating energy requirement) or out of risk considerations (e.g. new improved packaging technologies, excessively high risk potential of old concepts, sealing of the repository) that would be conceivable in several hundred years.

Regarding the long-term safety of planned deep repositories, scenarios of intentional or unintentional opening of, or drilling into, the facility give cause for concern. The main scenario for unintentional exhumation is drilling into the repository during future exploration for natural resources (including geothermal) or the injection of liquid wastes (Posner 1990, p. 44; Hora et al. 1991, p. IV-9 ff.).

Intentional human intrusion into a deep repository deals in the first instance with retrieval of valuable materials. The main one would be weapons-grade plutonium (Merz 1996, p. 29) or nuclear

fuel (Nagra 2002a, p. 140 ff.; HSK 2005, p. 93 ff.). Seldom considered, on the other hand, are scenarios of retrieval of other valuable materials such as native copper from copper canisters or steel canisters (Trauth et al. 1993, p. 4–6, Greenpeace o. J.). Such scenarios are well evidenced historically, as shown by the excavation of old ore heaps and re-use of metals. This long-term recycling principle through retrieval of buried waste is also followed, for example, in the underground disposal facility Herfa-Neurode (Hesse, Germany) (K+S Group, n.d.), although the diverse inventory of emplaced chemical waste will never be completely recycled.

Further intrusion scenarios include expansion of a closed repository, bomb tests underground, underground archaeological projects and construction of dams with underground infiltration (Hora et al. 1991). The intentional retrieval of waste for destructive purposes (scorched earth politics⁹, see B2) should also be considered in view of historical precedents (see section B2), even if this has been ignored to some extent up till now (Forinash 2002, p. 184).

Appraisal

The motives for intruding into a repository are understandable, familiar and generally recognised. The most likely scenario is probably the search for natural resources or other exploration or use of the underground environment; further possibilities are re-opening the repository for the purpose of expansion, sealing the facility, removal of valuable materials (canisters) or for moving the repository. A spatial planning order regulating the depth at which existing uses of the underground space occur could reduce the risk of unintentional intrusion. This assumes that such records would be systematically organised and transported through time, similarly to land and ownership registers. It is presumed that no protective measures will be effective against scenarios in times of social crisis (bomb tests, destruction, etc.).

A6 To what extent can the history of science and technology contribute to clarifying the question of the purpose of marking (particularly whether the question of the sense of marking is actually superfluous as the construction of the shaft and surface facilities already constitutes marking [i.e. fingerprints])?

Problem definition

A key question that repeatedly enters the discussion is whether marking at the surface could not ultimately put the safety of a repository massively at risk as it could function as an “invitation” to intrude into the facility. The main argument in support of this fear is the historically and archaeologically evidenced desecration of sites, mainly for robbery, which continues to the present day. On the opposite side, there is the question whether the accesses to a repository can be disguised in such a way that they would no longer be recognisable to future generations.

Information in the literature

This question is dealt with extensively in the literature. In principle, no site is protected from “grave-robbery”. Robbery generally occurs when there is the expectation of financial gain. For deep repositories, it is true today that inadvertent intrusion or penetration to a repository located at a depth of several hundred metres would be more or less pointless both technically and financially, even for a group of extremely well equipped grave-robbers.

The statements in the literature on the main problem are relatively clear, namely the question of intentional intrusion into a repository. Givens (1990, p. 95) rightly notes that many messages – from cave paintings to cuneiform writing and physical structures – are conceived primarily for contemporaries. There is however a fluid transition from this to information transfer involving much longer timescales that is also intended for future generations. Examples of this for all times and

⁹ Scorched earth: first coined in 1907 in connection with human rights, but describes well a practice that has been rife in war situations since time immemorial.

many cultures include national emblems, route markers and indicators of ownership, but also warnings for the future. Grinsell (1975, p. 94 ff.) has brought together encoded warnings, curses and prohibitions on different media from old cultures which clearly show that ancient cultures were fully aware of the phenomenon of desecration of structures containing something of value. These warnings were either of limited or no use. Where something valuable was to be found, it would be recovered later by humans, be it Etruscan graves, Egyptian mummies or sunken ships. Even financial funds have repeatedly been plundered over the course of history.¹⁰

At the same time, warnings have also survived for incredibly long times, even if they have had only little or no effect. The reason for this is often that decoding the warning is no longer possible or of any interest because the language or the script can no longer be understood or read (Sprenger 2007, p. 4). This can be seen clearly for hieroglyphs and cuneiform script that could only be understood after a tiresome deciphering process (Doblhofer 1993).

Other transmission pathways examples can be found in Japan. One example is the Ise Jingu Shrine located in Ise City, Mie Prefecture, estimated to be over 1,000 years old, which is being demolished and rebuilt every 20 years. The memory of the shrine is kept alive by the systematic renovation of the buildings. The tradition of the Shinto shrines is a very interesting example of a more or less functioning intergenerational relay practice (see chapters E2 and E4).

Secondly, we can think about the tsunami warning stones that should warn against building below a certain altitude. These stones are in some cases more than 1,000 years old and some of them are still part of the collective memory. NEA (2013) has examined the reasons for the compliance or non-compliance with the warnings on these markers. It seems that the modern faith in technology represents a paradigm shift, obliterating the historical memory of past generations. The report concludes that "the one lesson to be taken from Japanese experience is that there is no reason to assume that future generations will care at all, monuments or not, about the presence of a repository that has never reached out and hurt anyone" (NEA 2013, p. 5). Once again the importance of anchoring information in the local population is emphasized.

In the last decades, a large number of new methods for exploring the underground have been developed. The question whether, given the current state of technology, it would be possible to disguise a repository has to be answered in the negative (see B4). As history shows, man has tended in the past towards higher forms of organisation and more complex technology, despite occasional crises and the extinction of entire peoples. The horror scenarios utopian literature that draw strongly on old apocalyptic existential fears (Minois 2002) have largely proved to be unfounded (e.g. Huxley's "Ape and essence"; Wells "Island of Dr. Moreau"; see also analyses in Esselborn 2003). The everyday world moves along relatively pragmatic lines, as evidenced throughout human history by the ability to repeatedly overcome major crises.

Appraisal

Seen from the perspective of the history of science and technology, there is no fundamental argument against the marking of a deep repository. An analysis of the motivation for intruding into a repository shows that the motives are generally rather banal, being mainly lack of interest or simply forgetting, or for gain or recycling of materials. In times of crisis, destructive motives can of course come to the foreground. History indicates, however, that a site cannot be disguised over the long term and, given this, there is fundamentally no argument against marking. The technical design can be optimised to leave little room for human motivation to take marking out of the equation. Ultimately it will be up to future generations to decide whether or not they will respect the marking measures left by our generation.

¹⁰ For the history of financial speculation and raids on monetary funds, see Galbraith 1992, 2005a.

B Environment and underground (lithosphere)

B1 What changes in the environment and at the earth's surface have to be taken into account during the required containment time?

Problem definition

The list of potential effects on a marking system over long containment times is comprehensive. Many of the questions raised in this regard have been dealt with extensively in the literature (e.g. Gera et al. 1972; Geotech. Engineers 1980a; Geotech. Engineers 1980b; Fairbridge 1980; Milnes 1985). Particularly interesting insights into possible processes that could affect a repository can be found in Gera et al. (1972) and Milnes (1985) in connection with the discussion of near-surface disposal facilities. In this case, processes such as denudation and erosion, flooding, etc. play a key role in the exposure of a repository. Exposure of a geological repository requires different forces such as deep glacial erosion, volcanism or meteorite impact, which would partly or completely destroy the facility. The present study does not consider such events with maximum potential for destruction as repositories will be constructed outside risk zones or because a major event such as meteorite impact, with an effect to a depth of several hundred metres, would in any case destroy any marking strategy.

Information in the literature

As mentioned above, the geological, hydrogeological and other environmental hazards for a near-surface repository were listed at an early stage. Milnes (1985) approached this in a particularly systematic way, including all potential processes: processes effective at the surface such as soil formation, weather-related processes and climatic and fluvio-terrestrial effects. For weather-related effects, the spectrum of possible impacts is large, ranging from classical physical processes such as precipitation, surface run-off and groundwater formation through chemical effects (acid erosion, redox reactions, precipitation and crustal formations) and biological processes (humic and fulvic acids, vegetation, microbial activity, fungi, etc.) to plant growth and burrowing activity by plants and animals (cf. Milnes 1985, p. 99 ff.; Cadwell et al. 1993, p. 2.7–2.9). Similar considerations have also been made in the case of planning waste disposal facilities (e.g. Oberholz Suhr project, Aargau, planning documents 1989 to 1998; Gummersloch Köniz Bern, clean-up phase 1989 – 1992). The works cited are restricted to a description of the processes.

In terms of marking, the effects of environmentally driven processes have been addressed in concrete projects. Darnay et al. (1969, p. 119 ff.) made mention at an early stage of the interactions between waste and the environment in near-surface facilities and focused on the durability of the emplaced materials. At the beginning of the 1980s, the discussion shifted as a result of the work of the Human Interference Task Force (HITF 1984, Berry 1983, WIPP 2000; WIPP 2004a). Semioticians and archaeologists (Kaplan 1982, p. 8 ff.; TIFP 1984, p. 30 ff.) became occupied with the question of the durability of the messages and the carrier materials used and discussed these using archaeological analogues. Regulation promulgated by the United States Environmental Protection Agency in this respect (40 CFR 191/194) led to corresponding project developments (see Adams et al. 1986; Benford et al. 1991; WIPP 2000, p. 20, 23–25, 26 etc.; WIPP 2004a, p. 22 ff.), which foresee complex selection and test processes for carrier materials (see also B3).

Specific project-related research on the durability of carrier materials and possible environmental influences has not, however, been carried out conclusively. The marking system as a whole will have to fulfill different requirements depending on whether the discussion is about near-surface marking or marking of shafts and the deep repository (see B3).

Appraisal

The question of the effects of natural processes on the marking of a deep repository is well understood, particularly in terms of the materials used to transmit information and their lifetimes.

Questions regarding how this should be dealt with in concrete repository projects have hardly been considered at all, particularly the case of extreme climatic conditions or increasing use of available space.

B2 Can environmental and social crises¹¹ be sufficiently well predicted (historical studies) and extrapolated to make them relevant for the question of marking?

Problem definition

Environmental and social crises can have a direct impact on the safety of a geological repository. They can also be important for marking activities in two situations. In the first, it is conceivable that a crisis or serious disturbance during the operational period of a repository could partially or completely interrupt a marking programme, meaning that only part of the information would be available for posterity. In the second case, interruptions in establishing a marking or maintenance programme during a longer operational or post-operational phase could mean that significant parts of the marking strategy could lose their meaning. The question is whether such potential developments can be prevented.

Information in the literature

The connection between environmental intrusions due to human activity and their effects have been known in the broadest sense since ancient times, namely in the form of deforestation, erosion and influences on the climate (e.g. Plato's Critias dialogue¹²). The destruction of enemy territory common in the ancient world (see descriptions in Thucydides, the Peloponnese War; Flavius Josephus, the Jewish War, etc.) also shows that our forefathers were well aware of the devastating effects that man can have on his environment. This has continued into the nuclear age (Rhodes 1988; Jungk 1963; Zahn 1955)¹³. Only in the 18th century did people begin to examine this link between environment and society systematically (Buffon, de Saussure, Humboldt, Kropotkin; see Glacken 1988), continuing through the analyses of the Club of Rome global think-tank and the investigation of mechanisms of social collapse following environmental crises (see Diamond 2005). Social collapse was considered early on in the literature on radioactive waste (e.g. IAEA 1972) and was included as a scenario for discussion and development of marking strategies (Sandia 1991, Posner 1990b; Benford et al. 1991). From this awareness of social crisis situations, EKRA (2000) derived the need for rapid closure of a repository. If this is taken up and applied to a marking strategy, the question then arises as to the continuation of marking programmes in the case of environmental and social crises. Such questions could not be identified in the literature because perturbation scenarios during the operational period of a repository are not considered.

If a crisis situation were to arise during the operation of a repository, there could be fundamental changes in an adopted marking policy, in the sense that parts of the facility would no longer be marked or would be marked in a different way from that originally intended. For marking programmes, such intellectual games lead to the conclusion that actual implementation of an entire facility should take place within a relatively short time period in clearly defined processes and stages.

¹¹ Environmental crises in the sense of Karl-Heinz Hillmann's "Überlebensgesellschaft" (survival society) (1998), as the sum of all humanly induced changes in the environment with corresponding feedback to nature and man's living environment.

¹² Platon (1973): Critias, S. 287-300, in Hauptwerke, Verlag Alfred Kröner Stuttgart

¹³ According to Rhodes (1988, p. 519), Enrico Fermi suggested to Robert Oppenheimer, father of the Manhattan Project, in 1943 that radioactive fission products should be used to poison German food supplies. E.O. Lawrence, a physicist also involved in the Manhattan project, sought in 1949 to interest James Conant (member of the General Advisory Committee, Rector of Harvard University) in using radioactive dust in war situations. The idea of using radioactive waste as a weapon was apparently fairly widespread among military leaders in both the East and West: In the case of a war [between East and West, comment by M. Buser], US aircraft were to scatter radioactive waste over wide areas of West Germany. This would make it impossible for Eastern troops to penetrate through the contaminated zone (Zahn, 1955).

Appraisal

Environmental and social crises are important factors that can fundamentally change an ongoing marking strategy. The influence of such crises applies in the first instance to the implementation or the discontinuation of an advocated strategy. The risks of such a scenario can be reduced significantly by appropriate disturbance and risk management (see part E).

B3 What changes in the earth's crust could affect the integrity of the repository structure and its marking system (processes and properties)? In what way do the relevant sub-systems change: can we predict these changes sufficiently accurately based on historical studies and models? Are changes in the deep underground environment over the disposal period relevant for a marking system?

Problem definition

This question is relevant in connection with the requirement for retrievability of the waste. Marking of the facility would allow future generations, should it become necessary, to re-enter the repository. This raises the question of the durability of materials in different geological environments under potential influences. It should also be noted here that future generations could access a repository using different technologies and in different ways and will not necessarily follow the pre-defined paths. Given this, marking measures underground would have only limited relevance or none at all.

Information in the literature

As already presented in section B1, the different parts of a waste disposal facility are subjected to different forces and stresses. Aside from processes in the earth's interior such as earthquakes, deeper rock formations are significantly better protected from damaging effects than near-surface formations. Climate, hydrological regime and also biology can affect marking at the surface much more strongly than at depth. Down to a depth of around 1000 metres, it is mainly geochemical factors that are important for the aging of materials – and hence for marking.

The question of the lifetime of materials under external influences in the time period of 10,000 years (see below) is often addressed indirectly in the literature. Scientists, primarily archaeologists, made reference early on to the durability of materials used for marking (see B1, HITF 1984; Kaplan 1982; WIPP 2000; WIPP 2004a, 2004b). Some works also attempt to provide quantitative information on the durability of materials (Berry 1983; WIPP 2000 Tab. 1; Sugiyama et al. 2003), with the effective lifetime of a material being strongly dependent on the geochemical properties of its environment. The conditions underground are generally orders of magnitude less reactive than those at or near the surface.

A dry climate favours the preservation of buried organic materials for periods of up to thousands of years (finds of silk from Loulan, Silk Road; papyrus codices from Nag Hammadi, Egypt; leather and papyrus rolls from the Dead Sea, etc.). Wet, acid environments and the absence of oxygen can also preserve organic substances for thousands of years (e.g. peat-bog corpses). Preservation of such materials is, however, the exception rather than the rule. As soon as biologically active conditions dominate, the materials degrade very quickly and are not really suitable as media for long-term marking. Even their suitability as archiving materials (see "papier permanent" of Andra) is open to question.

Metals such as gold and platinum are also effectively resistant to weathering over a period of 10,000 years, as are silver, lead and copper (Berry 1983, p. 9-10). Iron and iron alloys, on the other hand, are highly susceptible to corrosion, as archaeological data show. The Roman helmet from Augusta Raurica in Switzerland (see Nagra information brochures) can undoubtedly be considered as one of the best preserved metal artefacts from ancient times. Alloys can often be long-lived, for example bronze and tin that have existed since the Iron Age. Modern alloys such as Hastelloy C, Inconel 625 or titanium could "survive" for 10,000 years (Berry 1983, p. 15 ff.). Various rock types (limestone and sandstone, marble, granite/gneiss) have also shown their resistance to weathering over thousands of

years. Earthenware is also very resistant, particularly stoneware (underground water pipes). Glasses show considerable long-term stability under chemically aggressive conditions, while cements can have very variable lifetimes. Overall, there is sufficient information to allow materials to be selected that are suitable for marking surface facilities and shafts and galleries deep underground for more than 10,000 years.

Appraisal

The natural processes that could compromise marking systems underground are well known. Archaeological evidence for the durability of materials near the surface is sufficient to allow materials that are resistant on the long term to be selected for a marking programme.

B4 Is it possible to disguise and close a deep repository in such a way that any reminder of intervention is permanently extinguished (potential for disguise)?

Problem definition

This question arises from consideration of the purpose of marking (see 01) and was addressed as part of the WIPP project (Benford et al. 1991; Benford 1999). Various requirements would have to be fulfilled for this to be the case. After final closure of the repository, all the surface structures would have to be removed and the site restored with its original geomorphological features. Measurable marking installations underground would also have to be dispensed with as these could be detected using sensors at the surface.

Information in the literature

Aerial photograph and satellite technologies have been in use for more than 100 years for exploring the earth's surface. The applications are wide and include mapping, modelling of morphology and relief, searching for water and raw materials, surveying legacy wastes and aerial archaeological prospecting. The use of different technologies (aerial and satellite imaging, infrared imaging, multispectral remote sensing such as spectrophotometry, MOMS-2, etc.) has advanced in the last decades to such an extent that even the smallest anomalies at the surface (shadows, differences in vegetation, snow drifts and frost, thermal reflections, etc.) can provide information on the composition and previous uses of the ground. Techniques such as aerial archaeological prospecting have also been successfully used in Switzerland over the last two decades. They allow systematic detection of buried objects from earlier times (from Celtic burial grounds, Roman villas and settlements from the Middle Ages to agricultural drainage systems and the use of sprinkler installations; Lasaponara & Masini, 2011; Castrianni et al, 2010).

As far as can be ascertained, this topic, particularly the question of camouflage, has only been touched on in the literature (Benford 1999), and not systematically analysed. This could be due to the fact that the question of actual marking technologies for repositories only arises for concrete projects and detailed technical questions will only be addressed at this more advanced stage.

The answer to the question of the usefulness of camouflaging shaft structures and repository accesses basically depends on the interest and potential of a society to secure and develop ground exploration technologies. The great advances in interdisciplinary remote sensing techniques and the linking of different technologies such as aerial imaging, satellite imaging, GIS, digital 3D modelling and visualisation make present-day perspectives for camouflaging the accesses to a repository somewhat irrelevant. The technologies for exploration deep underground (georadar, seismics, etc.) make it highly unlikely that, in the future, large underground structures would not be recognisable, particularly if they had magnetic or acoustic markers (Benford et al. 1991, p. 18-20; WIPP 200, p. 32 ff.). Added to this is the expected use of the deep underground (e.g. for geothermal energy), which could also result in a significant restriction of the disposal area. Safety aspects also have to be considered (metals and gas formation, see A3, C4).

On the other hand, scenarios of societal regression have also been discussed; these would involve a significant loss of modern technology. The development of marking systems (see Sebeok 1984; Tannenbaum 1984; Benford 1999) is actually based on such considerations for protecting future, technically “regressed” cultures (see Diamond 2005 and B2). In this sense, doing without surface marking would be the same as abandoning the marking principle itself.

Appraisal

A coherent marking policy without surface marking is practically impossible; the objectives and fundamental problems of marking would contradict one another in such a situation. Marking arouses curiosity and hence the risk of deliberate intrusion. No marking, on the other hand, creates a risk of unintentional intrusion. In this sense, no truly justifiable decisions can be derived either for or against marking at the surface. It remains open to the discretion of the repository planners and the implementing generation to decide what protection and information measures should be put in place. For technically “regressed” cultures in the future, there are no justifiable predictions of what marking could achieve. For technically advanced societies, the question is irrelevant as camouflaging the repository is not possible.

C Marking and repository structures

C1 Can the evolution of the repository structures be predicted (natural and historical analogues, scenario analyses, etc.) and hence the possible impact on a marking programme?

Problem definition

The question has to be approached differently for the different host rocks that come into consideration. For stable rocks, it is to be expected that not even coupled thermo-mechanical processes will lead to any significant deformation and that the repository itself will not really be influenced. The situation is different for plastic rocks, particularly salts, which deform rapidly with changes in underground stresses; these could be set in motion by a thermo-mechanical pulse emitted by the repository. In such cases, the structure or parts thereof, together with its contents, could “migrate”, which could lead to significant displacements in the case of creep movements in salt. Marking programmes underground have to take such phenomena into account.

Information in the literature

Geological processes occur at different rates. Large movements are to be expected primarily in seismically active zones and in the event of large earthquakes (in the order of cm/year or up to metres/event in the case of major earthquakes along large fault zones). However, if siting is based on a safety-oriented site evaluation, it can be assumed that a repository would never be located in such an active zone.

Focusing on Swiss conditions, and particularly on the geological siting regions in Northern Switzerland proposed by Nagra for constructing repositories, three phenomena have to be considered that could have a negative effect on a marking programme:

- Glacial erosion (see C2): Nagra (2002b) refers to an increased risk to the underground due to the formation of new glacial channels. Over-deepening of several 100 m has been identified between the alpine margin and Northern Switzerland along the old valley axes of glacial advances. Substantial deepening in the vicinity of a repository would theoretically be possible within 10,000 years if the climate were to cool rapidly and an interim warm phase followed after several thousand years. When selecting a site for a repository, particular attention will be paid to this potential threat. A repository in an exposed location would not be acceptable. Gully (vertical) erosion would, in principle, be possible in Switzerland. Areas potentially at risk along old glacier axes therefore have to be excluded in the site selection

process. If these conditions are met, deep marking systems would not be affected by such scenarios.

- Uplift: With constant average uplift rates of 0.1 mm/year in Northern Switzerland (Nagra 1999b), a high-level waste repository would be located 100 m nearer the surface after 1 million years. In 10,000 years, the average uplift of the total structure would be around 1 metre. Combined with surface erosion, it can be assumed that, in the worst case, the effect on the marking system would be marginal (e.g. shaft head area, see effects in near-surface area B1).
- Evolution of the structure: Large-scale stress changes in the underground environment also lead to relative movements of the rock deep underground. These movements should not be under-estimated, particularly during the waste emplacement phase. If the time period of 10,000 years is considered, however, such movements are irrelevant for stable rock formations. Another phenomenon that could be important for marking is thermo-mechanical effects on the canister, with potential sinking of the canister after the saturation of the bentonite barrier. Such “buoyancy effects” have already been described in the literature in connection with the sub-seabed disposal project (NEA 1988, p. 139-140). For marking, this is important only for the case of retrieval of emplaced canisters or fuel assemblies.

Appraisal

The evolution of the repository installations can be predicted relatively reliably, particularly after the repository has been closed. During the emplacement phase, the largest effects are to be expected due to stress changes in the rock. For repositories not constructed in plastic host rocks such as salt, such phenomena have only restricted effects. Marking programmes underground would be only marginally affected.

C2 What intrusion scenarios have to be considered for a repository (hazard analysis) and what marking measures are conceivable in this context? What marking technologies are foreseen for protecting the facility and its inventory from intentional intrusion without the intention to destroy, e.g. deliberate waste retrieval?

Problem definition

In principle, various intrusion scenarios applying to different timescales are conceivable (see A5, A3). The first type of scenario relates to accidental intrusion into the repository when exploring the underground environment, either from the surface or laterally (horizontal drilling, possibly also with branching [cf. multilateral drilling]). The second type is the deliberate and controlled exhumation (exposure) of the disposed waste in order to obtain raw materials (materials/energy), for storage of waste (e.g. CO₂ sequestration) or intrusion out of archaeological curiosity or for safety considerations.

The requirement for retrievability of the waste places new requirements on marking of the deep facility. Is the intrusion procedure for such cases to be made easier by setting markers? Are warning markers to be placed to allow canisters to be recovered more easily? Or is such marking superfluous as recovery of the waste would not follow the same path? And finally: can protection of the facility and its inventory from unintentional lateral intrusion be assured?

Information in the literature

The question of retrievability has been the subject of intensive investigation and discussion for decades (Buser 1998, p. 34 ff.). As in other countries (France, loi Bataille 1991), Switzerland has only recently anchored this in legislation. Article 37 of the Nuclear Energy Act states that an operating licence will be granted under the condition that retrieval of the waste is possible without major effort up to the time of closure. Article 11 of the Nuclear Energy Ordinance states that the repository is to be designed in such a way that measures to facilitate monitoring and repair of the repository or retrieval of the waste should not compromise the passive safety barriers after closure. Article 67 states that backfilling should be done in such a way that long-term safety is assured and retrieval of

the waste is possible without major effort. These provisions have a direct effect on marking programmes in Switzerland. If one looks at the experience with the clean-up of large special waste dumps in Switzerland (e.g. Bonfol, Kölliken), disposal caverns will have to be designed and marked in such a way as to make retrieval of filled waste canisters as straightforward as possible.

In the case where the repository is dismantled for re-use, relocation or denser packaging of the waste and also for clean-up (as for special waste dumps in Switzerland), marking in the underground installations can provide valuable assistance, although it is uncertain whether renewed opening would follow the existing closed accesses of the repository. Marking scenarios for such cases are seldom discussed in the literature (e.g. Pescatore et al. 2008, p. 27; Tolan 1993, p. 38 ff.; see details in C4). This could be because retrievability has become more of an issue only in the last decade.

In the last two decades, the possibility of near-surface protective barriers has been discussed. These would be located a few metres below the surface and take the form of capillary barriers, asphalt sealing, etc. such as are often found in landfill constructions (Melchior 1993). Extensive investigations (protective barrier) were carried out at the Hanford site in the 1990s of the last century, from conceptual principles (Adams M. et al. 1987; Tolan 1993) to detailed studies on the actual emplacement of the barriers (Asphalt Test Plan, Freeman et al. 1994), their functioning (evapotranspiration studies; Link et al. 1992) or monitoring activities (water infiltration monitoring [lysimeter tests]; bio-intrusion controls, etc.; Cadwell et al. 1993).

Appraisal

A marking programme cannot be designed to take into account all possible intrusion scenarios (particularly tunnel construction such as the Swissmetro project, multilateral horizontal drilling, mole miner, etc.). The possible threat to a deep repository through lateral penetration is certainly the greatest risk for a facility that is not marked at the surface. Presumably the most effective protection against lateral penetration is a relatively wide secondary safety perimeter at the surface, which would, however, greatly increase the cost and effort involved in surface marking (see below). Warning marking systems for this case are closely coupled to the structure. The requirement for retrievability implies marking programmes in the facility itself, even if dismantling of the repository will not necessarily be via the original access routes.

	Intrusion scenarios	Reference	Motivation	Required technology	Preventive measures
1	Unintentional drilling into a repository for economic reasons. Penetration is vertical or from the side (motivation e.g. gas exploration Forest Oil Weiach 2004, exploiting coal seams Permo-Carbon trough, water (Zurzach), geothermal, salt solution mining)	Kaplan 1982, S.3; HITF 1984, S. 4; Hora et al. 1991, S. IV-9; Posner 1990, S. 44	Search for raw materials, water, forgetting repository location or its danger	Rotary drilling from 1900 (spindle top 1901)	Near-surface marking
2	Unintentional construction of a storage facility (gas, oil), of tunnels (e.g. Swissmetro) or other underground structures (vertical or lateral penetration)	Kaplan 1982, S.3; Hora et al. 1991, S. IV-10; Benford et al. 1991, S. 20, Tolan 1993, S. 21	Search for storage capacity, forgetting repository location or its danger	Drilling technology 1900 Mining technology 1900 Tunnelling technology 1870	Marking near the surface, in access shafts and the repository possible; preventive measures using marking difficult if outside repository perimeter
3	Unintentional injection of liquid wastes (CO ₂ sequestration, liquid waste, etc.)	Hora et al. 1991, S. IV-10; NEA 1995, S. 57; Tolan 1993, S. 21	Search for storage capacity, forgetting repository location or its danger	Rotary drilling from 1900 (spindle top 1901)	Near-surface marking
4	Unintentional drilling into the repository or its surroundings for testing new weapons systems (e.g. underground nuclear weapons tests from July 1957 at the Nevada Test Site)	Hora et al. 1991, S. IV-12, IV-24; NEA 1995, S. 57, Tolan 1993, S. 21	Search for a test site, forgetting repository location or its danger	Rotary drilling from 1900 (spindle top 1901)	Near-surface marking
5	Intentional opening of the repository to emplace new waste	Hora et al. 1991, S. IV-10, IV-16;	Expansion or re-use of the repository	Mining technology, 20 th century	No preventive measures effective, or marking near surface, in the access shafts and the repository
6	Intentional opening of the repository to recover valuable resources (copper, steel, etc.)	HITF 1984, S. 3; NEA 1995, S. 57	Recycling of resources	Mining technology, 19 th century	Use of only non-recyclable materials (e.g. ceramics), additionally marking (surface, deep)
7	Intentional retrieval of the waste inventory due to a new spatial planning evaluation or risk considerations (no need for clean-up)	AEN 2002	Dismantling of the repository or parts thereof	Mining technology, 20 th century	Marking near surface, in the access shafts and the repository

Table 4.2: Overview of potential intrusion scenarios for a radioactive waste repository at a depth of 1000 m, required technology and potential preventive measures

	Intrusion scenarios	Reference	Motivation	Required technology	Preventive measures
8	Intentional retrieval of waste inventory to clean up underground environment	AEN 2002	Dismantling of the repository or parts thereof	Mining technology, 21 st century	Marking near surface, in the access shafts and the repository
9	Intentional drilling into a repository to harm a society (scorched earth policy)	HITF 1984, S. 3, NEA 1995, S. 57	Herostratism/fanaticism	Rotary drilling from 1900 (spindle top 1901)	No preventive measures are effective
10	Repetition	HITF 1984, S. 3 NEA 1995, S. 57			
11	Archaeological exploration or underground research	Hora et al. 1991, S. IV-11, IV-23; NEA 1995, S. 57; Tolan 1993, S. 21	Historical curiosity (treasure-seeking), underground research	Mining technology, 19 th century Rotary drilling 1900	No preventive measures are effective, or marking near surface, in access shafts or repository
12	Unintentional exploration of the underground in repository vicinity with a hydraulic short-circuit	HITF 1984, S. 3; Tolan 1993, S. 21	Search for natural resources, water, forgetting repository location or its danger	Rotary drilling from 1900 (spindle top 1901)	Prevention through marking difficult, if outside repository perimeter
13	Construction at the surface with impact on repository (e.g. large dams)	Hora et al. 1991, S. IV-12, IV-25;	Water supply, energy production, irrigation	Dam technology 20 th century	Near-surface marking

Table 4.2 (cont'd): Overview of potential intrusion scenarios for a radioactive waste repository at a depth of 1000 m, required technology and potential preventive measures

C3 What is the status of technology regarding different marking technologies at the surface and in the underground facility? Can the lifetime of different technical markers (physical, chemical or biological markers, etc.) be assessed realistically?

Problem definition

The question relates to the status of marking technology for concrete projects, particularly with regard to marking a repository at the surface or near-surface, as well as marking in the access infrastructure and the disposal system. The basis for designing marking systems is the risk of intrusion by future generations, as presented in numerous works (Cameron 1981; Hora et al. 1991; Trauth et al. 1993; NEA 1995; see also A5).

Information in the literature

In the literature, marking technologies are described in three different areas:

- Living environment: for the human living environment – and for the biosphere in the broadest sense - Bastide et al. (1990, p. 89) propose that marking should be assured via a large number of self-reproducing creatures. These living radiation detectors – for example cats – should be genetically marked in such a way that they are over-sensitive to radiation. Every contact with radiation would result in visible damage (e.g. marks on the skin of the animal). In this way, humans would be warned of the radiation in their vicinity. Biological marking by increasing the sensitivity of living creatures to radiation has not been developed systematically to date.
- Surface or near-surface facilities: most of the attention is focused in this area, particularly concerning the implementation of concrete projects (WIPP: cf. Hora et al. 1991; Trauth et al. 1993; WIPP 2000; WIPP 2004a, 2004b, Tolan 1993). The first concrete marking studies (Kaplan 1982, p. 48 ff.; Tannenbaum 1984, p. 11 ff., etc.) dealt mainly with conceptual questions, the content of the information to be transmitted and the requirements relating to durability of the materials used (see B1, B3, E2). At the conceptual level, the staging of information in different rings or levels was proposed (HITF 1984, p. 53; Tannenbaum 1990, p. 133 ff.) and this was later taken over by actual projects (cf. Trauth et al. 1993, Drack 2013). This staged system distinguishes the following levels: Level 1: general information that a danger or risk is present; Level 2: more precise information that the risk is in the form of a repository, with spatial characteristics of the facility; Level 3: detailed information on waste volumes, repository features, catalogue of risks; Level 4: detailed technical information, plans, tables, etc.

The concrete design of projects: comprises large marking elements (large surface markers) in the form of monuments with engraved information about the risk (for WIPP 48 monuments, WIPP 2004, p. 13, see D2) within and outside the perimeter above the repository; small buried disc-size underground markers (e.g. time capsules, Trauth et al. 1993, p. G-24) above the perimeter (footprint) of the repository; a dam construction (berm) at the outer footprint of the repository with magnets and radar reflectors (both of steel, see also Trauth et al. 1993, p. 3-9); two storage rooms in the berm; an information centre in the geometric centre above the repository footprint; a hot cell constructed in the former encapsulation plant that should function as an archaeological memory. Other configurations with four large monuments, an information centre and underground marking was developed for Yucca Mountain¹⁴.

¹⁴ www.ocrwm.doe.gov/factsheets/doeymp0115.shtml.



Figure 4.2: The past meets the future: menhirs, cromlechs and dolmens of Stone Age and markers of the WIPP project Photos from left to right and from top to bottom (Rosmarie Zurbuchen, Zürich): Clensy (Yverdon, original position) and Musée Laténium Hauterive (Switzerland), cromlech of Almindres and dolmen of Zambujeiro, both near Evora, Portugal, dolmen of Erzingen, southern Germany, Spikes, menacing earthworks and forbidden blocks from WIPP (from Trauth et al. 1993)

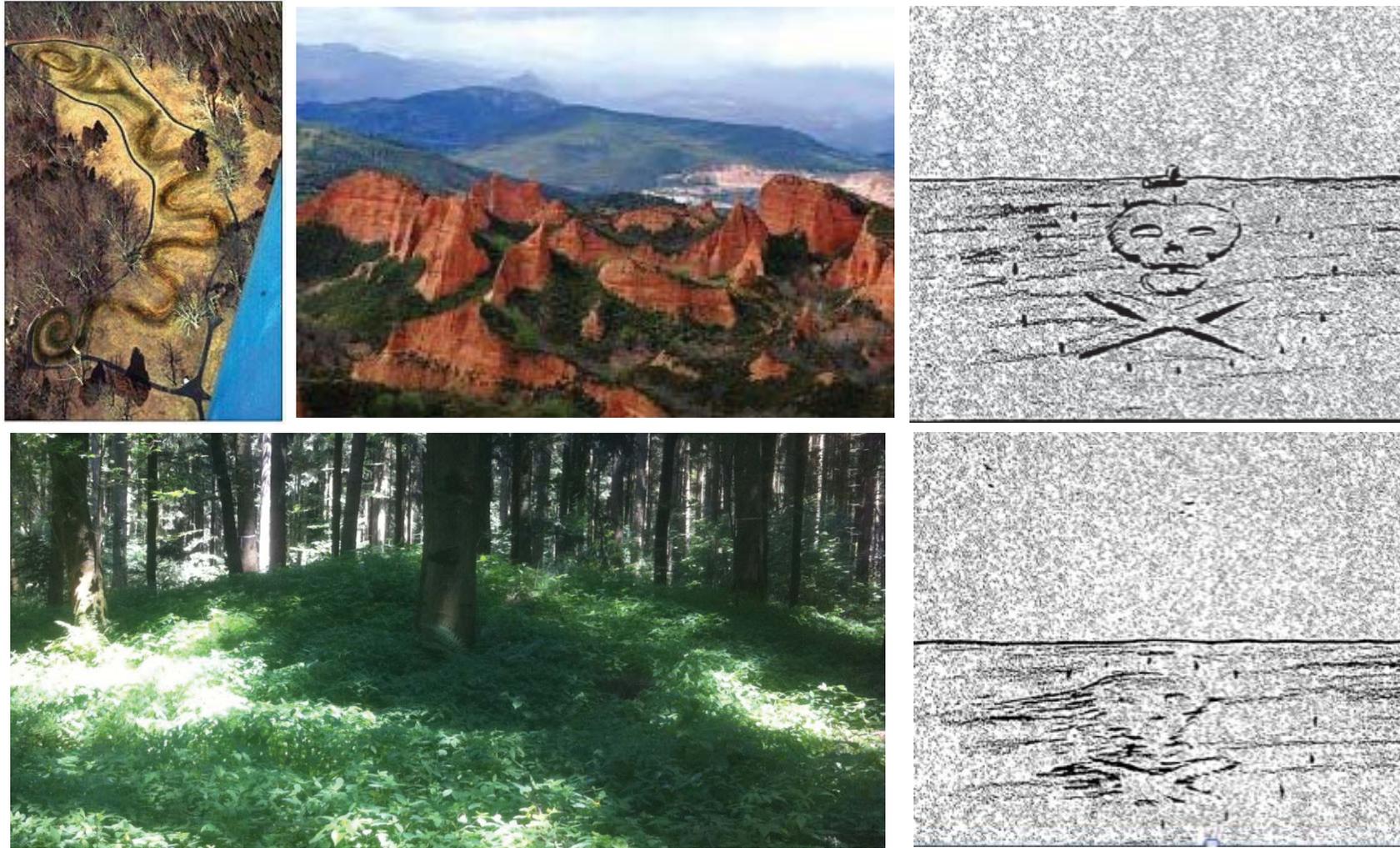


Figure 4.3: Historic landscaping and outlook for the future: an impression from large to small (top left: A snake figure from Effigy Mound, Ohio, USA, source: Wikipedia; Landscape of Las Médulas, León, Spain, former gold mining area from Roman times, source: Wikipedia; pre-Christian Celtic graves near Oberstadien, southern Germany, photo Marcos Buser). Right: Landscaping Project at WIPP: Skull and Crossbones used for earthworks at closure and after 5000 years (Trauth et al. 1993)



Figure 4.4a: Examples of the use of clay and ceramics, sources and reserved rights at the end of the report (from left to right and top to bottom). Top left: Venus of Dolní Věstonice, Czech Republic (replica from UrMu Blaubeuren, Germany), Photo: Marcos Buser; Top middle: Cavern of Yuchanyan, Hunan, China, <http://www.ncbi.nlm.nih.gov/pubmed/19487667>, Boaretto E., Wu X., et al (2009): web.bu.edu/asianarc/field.../fp_yuchanyan4.html; Top right: Jōmon-culture, Japan, en.wikipedia.org; Bottom left: Token from Mesopotamia (from Schmandt-Besserat D., 1996, 1999) and <https://webpace.utexas.edu/dsbay/index.html>; Bottom middle: Vinca culture, Danubia http://en.wikipedia.org/wiki/File:Vincha_066.jpg; Bottom right: Arabic tile, 13th century ? Spain, Photo: Marcos Buser

	Mark	Transmission area	Age (years b. common era)	Author	Function / Significance	Significance
Paleolithic terracotta figurine	no marks	Czech Republic	2,900 – 25,000	Vandiver et al. (1989)	Religious significance	Durability of fired ceramic Technical agility in ceramic production
Paleolithic terracotta pottery from the cavern of Yuchanyan	no marks	Hunan, China	18,300 – 15,430	Boaretto et al. (2009)	Found together with ashes	Durability of fired ceramic Technical agility in ceramic production
Paleolithic terracotta pottery Jōmon-culture	different patterns	Japan	14,000 – 7,500, older Jōmon		Purpose not fully understood	Durability of fired ceramic Technical agility in ceramic production
Token and terracotta bull	some marks with cylinder seal	Mesopotamia	8,000 to 3,000	Schmandt-Besserat D. (1999, 1996)	Contracts, counters, forerunners of the proto-cuneiform	Durability of the material (clay, ceramic) Durability and recognizability of the purpose and use
Terracotta pottery Donau-culture	ridges, fluting, engraving, lines etc..	Southeast Europe	6,500 and younger	Haarmann H. (2011)	Kitchen utensils and burial objects, marks as manufacturing and origin label	Durability of the material (clay, ceramic) Durability and recognizability of the purpose and use
After stone age	great variability of marks on clay objects	Eurasia	About 4,000 (Chalkolithic)	Various	Kitchen utensils and burial objects, marks as manufacturing and origin label	Durability of the material (clay, ceramic) Durability and recognizability of the purpose and use

Figure 4.4b: Examples of the use of clay and ceramics, sources and reserved rights at the end of the report

- The lifetime is determined by the durability of the materials and the recycling of resources (see B3). Hanford is oriented increasingly towards near-surface protective barriers (see C2).
- Disposal structures underground: there are different ideas as to how the underground should be marked, e.g. with large magnets, acoustic warning signals, rubber mats, coloured tracers, etc. (see C4). The different possibilities for underground marking were developed in the context of intrusion scenarios, but not for intentional retrieval. In the latter case, marking is only starting to be considered.

Appraisal

The range of ideas for the technical configuration of marking at the surface is enormous, well advanced and should develop rapidly as technology moves forward. For underground marking, the possibilities are not as well developed either in terms of the objective (retrievability) or the protection (lateral penetration) and the lifetime of underground markers (see B1, B3).

C4 Should packaging (e.g. canisters) and disposal caverns be used as marking elements?

Problem definition

This question is closely associated with the technical know-how available to a society. For “primitive” societies¹⁵, such considerations are obsolete as they are not in a position to correctly decode complex marking systems. The question is of interest for a technically advanced society. Using this strategy allows both the marking and, to some extent, the monitoring of a repository to be significantly improved (see C2).

Information in the literature

The idea of marking structural components underground was developed relatively early on in connection with intrusion scenarios. The proposed technologies for marking underground focused almost exclusively on the warning function and only rarely on aspects of technical feasibility or long-term safety.

There are diverse ideas as to how the underground could be marked (Bastide et al. 1990; Benford et al. 1991; WIPP 2000), for example with large magnets (Benford et al. 1991, p. 19ff., intrusion scenarios: mole miner), radiation markers with a selection of radioisotopes (Raimbault et al. 1993, p. 216) or acoustic warning signals (Bastide et al. 1990, p. 93-94), such as equipment that generates strong echoes¹⁶. Echo equipment inside the repository could be modulated by refined sound systems in order to signal the distance of the source of danger and confuse human and non-human intruders. In the repository itself, Bastide et al. (1990, p. 92) consider the marking of the waste containers with the radioactivity symbol using conventional pictographic methods. Consideration has also been given to characterising the packaged waste in its environment (Hugon et al. 1993) and marking the canisters (ONWI 1987, p. 14-15), but primarily for identifying and tracing the content and not really for marking purposes.

Tolan (1993, p. 38 ff.) presented various possibilities for marking disposal caverns and containers. The caverns could be equipped against borehole penetration using armouring or other protective measures at the tunnel roof; these would resist a drill-bit (rotary drilling) and would prevent further drilling activities or make them difficult (Tolan 1993, p. 39); they include rubber mats, rubble, metals or other materials. NST (2007, p. 2 ff.) has recently followed up this idea. Introducing metals would be excluded for reasons of corrosion (NST 2004, p. 4). Organic materials such as rubber mats do not

¹⁵ “Primitive” in the etymologically correct sense of original (from the Latin “the first of its type”).

¹⁶ By way of qualification, it should be noted that it could be difficult to produce sound-generating objects that would still be functional after 10,000 years, although, in principle, ocarinas made of dried or fired clay or flutes made of horn could remain functional over such time periods (Palaeolithic flutes).

belong in a repository as they can lead to gas generation (KSA 2005, p. 31-32). Hard rubber (vulcanite) becomes brittle in chemically aggressive porewater and is subject to bacterial degradation (De Cannière et al. 2009, p. 73). Introducing rubble would not meet the safety requirements in terms of the permeability of the disposal zone (Nagra 2008b, p. 59-60)¹⁷. Reference is also made to the extreme technical difficulty of introducing materials into a disposal tunnel that is 800 m long and 2.3 m in diameter (Nagra 2002).

ONWI (1981, p. 8 cited in Tolan 1993, p. 40) proposes using a chemical dye in the backfill material¹⁸, which would colour the drilling mud in a rotary drilled borehole. NTS (2007, p. 1) has taken up the chemical marking of the underground according to ONWI (1981) and Tolan (1993). The durability of tracers under the different interactions in the disposal zone and under the influence of radioactivity is not addressed in the literature considered. NEA (1995, p. 44) also mentions radioactive markers and spherical objects that would be geophysically recognisable.

The DOE (1987, p. 5-28) proposes placing ceramic warning markers underground. This idea is interesting, particularly in connection with retrievability, as such warning markers could indicate the distance to the effective disposal chambers.

Appraisal

The idea of using packaging such as canisters or disposal chambers as markers is not yet sufficiently well-defined or discussed. This gap should be closed, particularly in connection with monitoring programmes. The marking of waste containers is meaningful because it facilitates the retrieval of waste and fulfills a certain seal function. On the other hand, introducing foreign materials such as rubber, rubble or large amounts of metal into the repository should be avoided as this could compromise safety.

D Marking and information transfer

D1 How can active and passive marking systems be distinguished? Have active marking technologies and trading systems been considered systematically in all areas?

Problem definition

The strategy of warning future generations is based on two pillars: on the one hand, the structure should be marked against human intrusion using passive engineered measures (see C2 to C4), in such a way that there is as little maintenance involved as possible. On the other hand, marking should contain concrete messages for future generations and ensure that this information transfer can be assured over time. In this sense, future generations play an active role in transferring information into the future. This approach raises the question of information trading technologies, their completeness and their durability.

Information in the literature

The differentiation between active and passive marking systems is fluid. Engravings or inscriptions on materials such as stone, clay or metal are subject to the same stresses as the medium itself (see B1). Possible loss of quality of the medium used has to be compensated by monitoring the information medium, maintenance and repair. In this sense, passive markers are subject to some extent to “active” accompanying measures. The need for such measures for maintenance purposes is clear from the case of archiving using organic materials (paper, papyrus, leather) and, more recently, electronically stored information (cf. internet under keyword “long-term archiving”).

¹⁷ Rubble does not fulfill a barrier function; see the requirements in the Sectoral Plan, criterion 1.2, hydraulic barrier effect (Nagra 2008b).

¹⁸ For example tracers used in hydrogeological studies (for organic tracers, see Käss 2004).

Three areas can be distinguished in which active measures are required for preserving knowledge (Figure 4.5):

- Designing, preserving and transferring information content: This focuses primarily on the fundamental possibilities for transporting information over time. It includes form and material selection, designing a facility and information media, as well as technically error-free copying of messages through time (see E3). Early studies on marking (e.g. Tannenbaum 1984, HITF 1984) referred to some of these points. International bodies have also drawn up recommendations for preservation of knowledge over long times (IAEA 1999, IAEA 2001, IAEA 2004; see also D2 and D3).
- Transfer of the information content (knowledge trading): If knowledge preservation is assured through the durability of information media and copying of messages, the question arises as to the transfer of information content and knowledge trading within and outside a specific cultural group. Fundamental problems in knowledge trading over long times were recognised and discussed at an early stage (Kaplan 1982; Hora et al. 1991). Verón (2004) looked at the sociological context of semiotics and the dependence of knowledge transfer on ideology and power. It is also important in this regard to understand how knowledge can be lost over historical timescales (cultural erosion and rupture) and what societal and cultural processes can be involved (see D3).
- Structural measures for knowledge trading: Here the discussion centres on the structural requirements underlying knowledge transfer that have to be assured in order for knowledge trading to occur at all with the technically desired level of quality. In the foreground are structural-sociological and historical issues, such as the suitability and stability of social structures, historically evidenced structures over time and their susceptibility to errors, organisational forms of a knowledge-based society, economic factors for ensuring continuity, etc. These issues have been raised by various authors in the literature considered (see Pescatore et al. 2007; Sebeok 1990, Blonsky 1990, D4).

Important in this context is the point that preserving knowledge about geological repositories over time requires measures in all three of the above areas. Organisational structures and rules alone are not sufficient to ensure information transfer over historical time periods.



Figure 4.5: When past meets future: comprehensibility of objects and symbols through time (explanations see next page): left : objects (32 000 – 40 000 y old), pictures (up to 9 000 y old), menhirs (up to 6 000 y) and restored inscriptions (2 000 y old) right: iconic-symbolic illustrations, icons, pictures and warning text

Explanation of the pictures and images of figure 4.5: When past meets future: comprehensibility of objects and symbols through time

Some examples of past illustrations:

- Top left: Lion Man (Asselfingen), around 32'000 y, unknown significance; Urmuseum Blaubeuren, photo M. Buser
- Second from top left: Red mineral pigments, used before round 35'000 y, Urmuseum Blaubeuren, photo M. Buser
- Third from top left: Flute made from mammoth ivory, cavity of Geissenklösterle near Blaubeuren, 35'000 – 40'000 y, Urmuseum Blaubeuren, photo M. Buser
- Middle left: rock paintings from the Lower Stone Age, unknown significance, Tassili, southern Algeria
- Second from middle left: rock paintings from the Lower Stone Age, capricorn, Cova Remigia, Ares del Maestre, Castellon, Spain, photo Rosmarie Zurbuchensee: Sarria-Boscovich Elisa (1989): Las pinturas rupestres de Cova Remigia, Ares del Maestre, Castellón, Spain, Lucentum, VII-VIII, http://rua.ua.es/dspace/bitstream/10045/4429/1/Lucentum_07-08_01.pdf
- Bottom left: menhir rows in Clensy, Yverdon, Switzerland, original position, unknown significance, photo M. Buser
- Second from bottom left: Roman inscription of Pierre Pertuis, Tavannes, Neuchâtel, Switzerland, photo M. Buser

Some examples of paintings, writings, symbols and iconic-symbolic used for warning or prohibition

- Top right: New radiation symbol, comprehensibility doubtful in time, from ISO 21482
- Second from top right: iconic-symbolic illustration of radioactivity decrease in the time, comprehensibility doubtful in time, from Trauth et al. (1993)
- Middle right: Multigenerational warning signs, Effects of Radioactivity over Time, comprehensibility doubtful in time, from ISO 21482
- Second from middle right: Edward Munch, The Scream, comprehensibility doubtful in time, from http://www.amb-norwegen.ch/FileCache/PageFiles/317252/skrik_300px.jpg/width_300.height_375.mode_FillAreaWithCrop.pos_Default.color_White.jpg
- Bottom right: Prohibition sign “placing your hands”, comprehensibility doubtful in time, DIN 4844-2
- Second from bottom right: Detail: Example of an incorrectly translated warning text in Spanish, comprehensibility doubtful in time, from Trauth et al. (1993)
- Since 2013, the subject „past – future“ is also shown in the exhibition at the Museum of Allerheiligen, Schaffhausen, Switzerland, October 2013 – March 2014 (Jelzer et al. 2013)

Appraisal

As already shown for questions relating to marking technologies for the facility, an overall treatment of the trading of knowledge content is essential. While technical and semiotic topics have often been considered, consideration of structural issues is relatively far behind today.

D2 What should be transferred and how? What design possibilities does marking offer at the surface in a large area above the repository (macro-level)? Can such a design be transferred independent of time?

Problem definition

What information should be transferred? How should information on the existence of a repository be transmitted to future generations? How can their attention be drawn to the presence of the facility on the long term? What design measures are available for transferring information? How can information be preserved over long times through design measures and material selection?

Information in the literature

What information should be provided to future generations? This question has long occupied scientists in the context of marking programmes. From an early stage, research in this area divided the information into different levels (HITF 1984, p. 92 ff.; Sebeok 1990, p. 154 ff.; Voigt 1990, p. 123 ff.; Givens 1990, p. 95 ff.; IAEA 1999, 2001, 2004, see also 05, C3, D3). Eng et al. (1996, p. 35, 51 ff.) listed potential information sources (laws, information about the society that emplaced the waste, safety analyses, waste data, information on the repository, etc.), but did not discuss them in detail. The same can be said of other information sources that deal with long-term archiving of deep repositories (e.g. IAEA 1995, p. 42) and always lead back to the question of how a relaying system can be set up that will ensure information transfer (Sprenger 2007, p. 61). The question of the concrete selection of information cannot be answered definitively today. For L/ILW repositories such as Centre de la Manche and Centre de l'Aube in France or Celda de almacenamiento del Cabril in Spain, information on the waste inventory and the facility itself is preserved in archives at the site and with special institutions, but the details of the long-term archiving are not specified.

The “how” of information trading – in contrast to “what” – has been well developed in concrete projects for repositories (see possible configuration of a surface marking system for the WIPP repository [WIPP 2004b] in C3). Configurations of structures that take account of topographical and morphological properties have also been developed as part of other projects (figures in Gaus et al. 2009, p. 22; Blonsky 1990, p. 172; Tolan 1993, p. 27). The spatial arrangement and configuration of the surface facilities have an impact on the morphology of the landscape. The layout of the components also plays a key role, as archaeological experience shows (e.g. arrangement of the Stonehenge monoliths, UK; geoglyphs of Nazca, Peru; the Great Serpent Mound, Ohio, USA; Great Wall of China, cf. internet). What function these arrangements fulfilled has not been clarified in every case. For other historical structures such as temples, fortresses and defence walls, there is often repetition of a basic pattern in the arrangement of the buildings, independent of culture (e.g. temples on hills; fortresses on defendable mountain ridges; aqueducts).

The potential for spatial arrangement of the surface facilities of a repository is recognised in the literature as an element of information transfer (Kaplan 1982, p. 48 ff.) and has been used in concrete planning of marking projects (see above). In these projects, monuments were also conceived as “objets d’art” designed to awaken special interest. The painter Anton Lehmden of the Vienna School for fantastic realism selected a futuristic approach with the “atomic egg” project. The objective was to build a cultural bridge between industrial technology with its waste and the environment (NEA 1992, p. 41). The L/ILW from Austria was to be packaged in special egg-shaped containers and placed in the landscape. Lehmden saw his eggs as symbols for the existence and interaction with highly

industrial waste products. The approach of seeing deep repositories as cultural sites is shared in a religious to ideological sense by large parts of the “guardianship movement”¹⁹ (Buser 1998).

The approach of Lehmden, that sees waste as a cultural property, leads to marking also being considered from the perspective of the architecture and design of facilities and cultural landscape. Besides formal and functional aspects of the design, this also includes the aesthetic composition, choice of materials and colours, the relationship between the elements, etc. In this case, it is important to couple the warning function of the marking system and the information content. Several authors (Kaplan 1982, HITF 1984, Sebeok 1984, etc.) adopted the approach in the early days of making different warning stages and information levels of the marking structures clearly recognisable (see also 05 and C3).

Appraisal

The questions surrounding the technologies for preserving knowledge are, from a purely technical viewpoint, covered well by various institutions in the nuclear field. The potential problems of long-term archiving and strategies for overcoming these are well known. Organisations such as the IAEA, the NEA and waste management agencies of different countries generally assign high importance to the question of record preservation.

Marking concepts and their configuration in the context of information transfer at a concrete site are fairly far advanced. What remains uncertain is the aesthetic relevance of structures and memorials as a means of transmitting a warning function and their durability over time. The risk of distortion of messages due to cultural and aesthetic change should not be underestimated.

It is important to note that an aesthetic approach to marking is imprinted by the subjective cultural perception of a time. Memorial sites – as known from concentration camps and military cemeteries – raise contextual questions, namely whether the intention of a memorial is still recognisable if societal values change. Whether maintaining or copying of aesthetically conceived marking structures can be assured over time under these conditions is doubtful (see E3). It has to be expected that the warning function of a marking project will change over time in terms of design and the content could thus be falsified.

D3 What technologies are foreseen for knowledge transfer (knowledge management, trading technologies, codification technologies, etc.)? How can we assess today how these technologies will be preserved with time?

Problem definition

The transfer of information over long time periods presumes a comprehensive understanding of semiosis. Information has to be encoded, stored and then decoded, which raises numerous questions in the context of what is a long-duration process. It also has to be assumed that the context of semiosis - in other words the boundary conditions on which communication through time are based – will change fundamentally (see E1). The complex interplay of environmental, social and economic factors and associated cultural features influence the content and form of the warning message and its comprehension.

Information in the literature

A wealth of knowledge has been brought together on technologies for knowledge trading in the fields of archaeology, ethnology and cultural anthropology (Watson 2005); this could be applied in the context of concrete marking studies and projects. The dependence of knowledge trading on context is clearly recognisable from a historical examination of the development of human culture. The increasing complexity of information transfer can be seen in the different stages of development of

¹⁹ Nuclear guardianship: anti-nuclear movement that originated in the USA and called for permanent storage of radioactive waste under the care of society.

the written and spoken word. Simple drawings, impressions and engravings on animal bones, cave walls and rocks from the earliest history of man were followed by more complex images and stories, later by more abstract pictograms and ideograms, and culminated in the coded writing techniques known from Mesopotamia of the Bronze Age (Haarmann 1992, 2006). Artworks (see D2) are further means of transferring information. Finally, the knowledge has to be preserved by maintenance and archiving (see D2).

The technologies for information transfer have been considered as part of marking projects. Givens (1990, p. 98 ff.) analyses the semiotic properties of early historical messages and draws up a list of seven key points to be considered in the marking of geological repositories (Givens 1990, p. 106-107, 117 ff.). These include using iconic symbols and pictographic representations, using narration principles (stories) and various languages and scripts, using large monuments, ensuring redundancy through opulence and repeated use as protection against decay and vandalism and, finally, supporting information. These points appear repeatedly in the literature: various authors (Hewitt, cited in Posner 1990b, p. 44-45; Sebeok 1990, p. 154 ff.; HITF 1984, p. 38 ff., Trauth et al. 1993) have prepared strategies for communicating using illustrated stories and pictograms for warning future generations. Trading systems that are closely linked with language and value systems are also mentioned (myths, stories, poetry and proverbs, artworks [Bastide et al. 1990, p. 88-90]). Pescatore et al. (2007, p. 3) underline the redundancy of information, for example the importance of duplicates.

In parallel with these efforts, various organisations and authors developed strategies for transferring and preserving information (record preservation, see Eng et al. 1996; Sugiyama et al. 2003; Ohuchi et al. 2003; NEA 2007), highlighting structural, strategic and technical factors. Preservation and transfer of information relate mainly to the transfer of detailed information, particularly on the inventory of the repository, the facility characteristics and the risk catalogues (information level 3, see C3), as well as detailed technical information with plans and calculations (information level 4, see C3)²⁰. In terms of structure, proposals have been made for handing over responsibility to an institution specially created for the purpose (see D4, E4). Preserving and transferring information on levels 3 and 4 have the same objectives: simple, robust and long-lived systems, selection of durable materials (e.g. sintered materials based on silicon carbide, aluminium or zircon), durable engraving technologies (Sugiyama 2003, p. 26 ff.), long-lived preservation methods (particularly for organic materials, e.g. "papier permanent", microfilm, digital media, etc.; see Eng et al. 1986, p. 53-74), a favourable storage milieu that considers environmental factors, permanent storage technologies on site or decentralised relay systems at various locations (archives, Bastide et al. 1990, p. 88; NEA 1995, p. 41 ff.) and periodical reproduction of information (Tannenbaum 1984, p. 9 ff.).

The distinction between long-term information transfer on site (information centres and marking, e.g. Trauth et al. 1993, partly with support of local trusteeships, cf. Pescatore et al. 2007) and off site (archives, Eng et al. 1996) is central from the point of view of redundancy and susceptibility to perturbations (E4).

Appraisal

The information in the literature is exhaustive on this topic. Marking technologies can be used in practically any technical area and for all possible social trading systems. The number of possibilities for applying or implementing these technologies is broad and presumably covers all conceivable scientific fields. These possibilities will continue to expand in the future with the development of knowledge and technology.

The question of changes in information content during encoding and decoding is more difficult to answer. This value shift could be acknowledged during the encoding process, but it remains open whether this awareness will be present in the future during decoding²¹.

²⁰ Level 3: detailed information on waste volumes, repository characteristics, risk catalogues; Level 4: detailed technical information, plans, tables, etc.

²¹ Open future according to Karl Popper.

D4 What social structures have to be considered for concrete knowledge trading on a repository? Is experience with historically stable structures (e.g. institutions, bodies) relevant in this context? Can local communities perform this “memory” function over long times?

Problem definition

If knowledge about a repository is to be preserved, monitoring and maintenance of facilities or system components and transfer of knowledge have to be assured. In turn, this requires corresponding institutions to be created or maintained and these tasks to be performed on the long term and without significant interruption. Such a long-term relay system for knowledge transfer also requires societies and social structures to be stable and historical experience with so-called “stable” institutions would have to be considered. It should also be considered whether such a relay system should involve local communities.

Information in the literature

Since Alvin Weinberg’s “Social Institutions and Nuclear Energy” (Weinberg 1972), the question of transferring information on a risk technology over generations has been considered socially on a broad basis. The follow-up to guardianship of the waste is now guardianship of knowledge over long times. Following the zeitgeist of the years of nuclear awakening and the sense of mission of a “believing” community, the pro-nuclear alliance was convinced that it could take over the role of knowledge-bearer for all time. The ‘Faustian pact’ made by the nuclear community led to the justification of an “atomic priesthood” as proposed by Weinberg (1972, p. 33-34). Sebeok (1990, p. 167) endorsed this vision with a similar mandate to a body for long-term transmission of information about the repository – a proposal that earned him harsh criticism from nuclear opponents (Garfield 1994) and was also questioned by semioticians (Blonsky 1990, p. 173 ff.). Other authors formulated the role of the knowledge guardianship elite somewhat more carefully: Voigt (1990, p. 123) termed them “news guards”, Bastide et al. (1990, p. 87) as the “happy few” that would still have knowledge of a repository. Others (Hammond 1979; Tannenbaum 1984, p. 26) spoke of a renewable system to be implemented every 100 years or so (relay system). In the last 15 years, the USA has decided in favour of such a relay system termed “long-term stewardship” (Tonn 2001; Pastina 2004; Sprenger 2007, p. 62 ff.; DOE 2007, p. 3).

Besides the Faustian pact of the nuclear community (Weinberg 1972, p. 33-34), Weinberg (1999) brought a second essential term into play - scientific millenarianism²². Weinberg’s fall-back to millenarianism and its vision of a religious-scientific trading of the nuclear legacy is linked to old utopian world views of the Enlightenment, such as the proposal of Saint-Simon to create a scientific papacy (Saint-Simon 1813/1973, p. 246 ff.)²³. The creation of stable social structures assumes the creation and implementation of normative rules and cultural codes. The implementation of such norms and codes by a specific institution over time requires canonisation of information and hence of language, form and content. It is exactly at this point that long-lived religious institutions such as churches have problems because the canons and codes to be transferred no longer endure in a new value system. The trading of information using millenaristic structures is therefore doomed to fail.

More appropriate is the approach of winning over local communities for such tasks and seeking other ways to pass information between generations. Steering bodies such as the US DOE and the NEA are thinking today of strategies for setting up an active socially supported relay system that involves local communities (cf. Pastina 2004; NEA 2007; Pescatore et al. 2008). The approach of constantly renewed encoding (recoding) of information bears the risk of erroneous coding and loss of information (see E3). Ways have been highlighted in which part of this information could possibly be transmitted by rituals, legends, myths and folklore manifestations (Sebeok 1990, p. 161 ff.).

²² Background texts that provide an understanding of millenarianism and utopia: Cohn 1961, Minois 2002, Cioran 1979.

²³ See the proposal of Saint-Simon on creating a scientific priesthood.

Appraisal

The question of trading information by an active institution or body is one of the most difficult. Decisions on how such institutions and bodies should be designed and function are in their infancy (e.g. Tonn 2001, p. 265 ff.; NEA 2007). The approach of coupling supranational bodies and siting communities for long-term knowledge trading does, however, open up possible perspectives.

E Susceptibility of the marking/trading system to errors and perturbations**E1 What requirements have to be fulfilled to ensure that communication does not fail over time? Can risk catalogues capture and describe the various possibilities for failure sufficiently well?***Problem definition*

The large time spans between the encoding and the possible or likely decoding of a message make it imperative to store the content. The message must be transferred to a medium that can be stored and, if necessary, renewed over long times. Historical experience shows, however, that significant – if not complete – loss of information is likely with time. While encoded information is time-invariant and the content is set and unchangeable, neither the recipients of a message nor their cultural background will be known. It can be assumed that cultural change will strongly affect the decoding of the message, not only in the sense that the recipient has flexibility in terms of interpretation, but also in the sense that knowledge and understanding of the world will change (see E3). There is no continuity in the construction of truth, particularly in a world that is constantly re-inventing itself scientifically. Truths change over time, as we can see from the history of philosophy and science. For communication over long times, it is essential to understand the processes and mechanisms that could lead to a loss of information and to identify erosion and rupture situations that lead to information loss or misinterpretation. In technical terms, a perturbation analysis in the communication field is required.

Information in the literature

The analysis of susceptibility to errors and perturbations in communication follows the levels distinguished for the marking systems (see D1). Susceptibility to errors and perturbations in communication can occur in three areas that can mutually influence one another:

- Perturbations during encoding, preservation and transmission of the information content: these cases deal essentially with the formal composition of a message, its completeness and understandability and its preservation over time. Problems can arise already in the encoding of a message, for example due to misconceptions and errors in transmission. Examples include incomplete understanding of the long-term risk, selection of unsuitable media for transferring the message, incomplete encoding of important content or errors due to carelessness, disinterest or manipulation. The problems associated with long-term archiving should also be addressed here, as well as intentional or unintentional transmission errors. The range of possible perturbations is wide.
- Perturbations during decoding of the information content: the process is the opposite in this case, namely interpretation and transmission errors arising, for example, from a change in social conventions or language and script (E3). A wide spectrum of human imperfections that can lead to totally different interpretations of a message also has to be considered here: greed and maximisation of profit are powerful driving forces that ignore all warnings, as is clearly evidenced by grave-robbery and ruthless exploitation (Grinsell 1975, Galbraith 1992, 2005a); poverty and misery that lead, in poor countries, to serious accidents with radiation sources, e.g. theft of sources from hospitals (IAEA 1988; IAEA 2001; IAEA 2002); fanaticism and political

megalomania as evidenced by historical examples since ancient times (see “Der Kleine Pauly”, II, p. 1110; IV, p. 71 ff.; von Choltitz 1950); but also lack of interest, carelessness and ignorance.

- Contextual change in culture: to be mentioned here are the loss of contextual cultural background, the potential for misinterpretation due to loss of knowledge and cultural change, manipulation of a message, etc. In this regard, the question is the susceptibility to errors of a message due to a change in the social and cultural background of future societies. Sebeok (1990, p. 152 ff.) and Sprenger (2007, p. 12 ff.) have stressed the contextual dependence of a message on the environmental conditions, including social conventions, value scales, linguistic change within societies, erosions and ruptures within social structures and large paradigm changes, e.g. of an ethical-religious or economic-political nature, etc. (see E2, E3, E4).

Appraisal

Susceptibility to errors and perturbations of marking and trading systems are well known by many authors, but have not been treated systematically or completely²⁴. This task represents a considerable challenge, both in terms of highlighting the content of future possible decoding problems as well as recognising and describing contextual change. It could also provide interesting conclusions about the sense or purpose of marking or trading systems proposed today.

E2 To what extent can marking systems be repaired or corrected (maintenance)? How susceptible are marking systems to errors?

Problem definition

The objectives and boundary conditions of a project often shift over the course of time. This can result in changes in the requirements to be met by a marking system. The question then arises of correcting and complementing marking systems, not just from a technical perspective but also from the viewpoint of social change. Added to this is the historically well documented shift in cultural identity that, in the event of major historical change, goes hand in hand with significant disruptions in culture and values. All trading systems based on semiotic processes are thus confronted with two questions: Can the ability and interest of future generations for monitoring, maintaining and complementing marking systems be preserved? What social and technical shifts could cause changes in the interpretation of content in the decoding of messages?

Information in the literature

Effective marking systems theoretically have to cover all conceivable scenarios of human intrusion. For the closed parts of the disposal system – the repository itself and its accesses – marking systems would no longer be accessible after closure. The same is true for markers that are buried near the surface, e.g. beneath a 2 metre thick covering layer (cf. C3, D2). The question of repair and maintenance is thus relevant only for accessible parts of the marking system at the surface. This has been treated extensively in the literature (see A5, C2, C3, D2, D4).

Information in the accessible part of a facility can be lost rapidly without maintenance (cf. D2, D3). Materials that are considered to be re-usable will presumably be retrieved (A5), engravings have a limited lifetime and climate effects and social developments can fundamentally transform the surface environment – as history has shown. If surface facilities such as those at WIPP are to remain intact, maintenance and repair will be essential. Whether this can or should be done over longer time periods depends on economic and intangible factors (e.g. risk perception, availability of financial resources, affectedness). In the area of conventional waste disposal technology, state organisations are entrusted with these monitoring and maintenance responsibilities (see D4).

²⁴ For example, such conditions were considered systematically only for intrusion (Hora et al. 1991; IAEA 1995).

Gradual disintegration of the marking measures at the surface would not have any direct impact on safety, but the warning function would be removed and the risk of unintentional intrusion increased (see C2 and C3, see also Table 4.1).

For “buried” marking systems, the risk lies in erroneous conception or qualitatively insufficient material realisation of the concept (see E3). The greatest risk in this respect is a change in values over time. Sebeok (1990, p. 152) and Sprenger (2007, p. 12 ff.) have highlighted this risk in the widest sense (see E3).

Even long-term memory (record preservation) is subject to similar erosive forces. The question is not only the natural durability of materials (references in B3) – social stability is just as important for knowledge transfer. History tells us that the list of actions aimed at extinguishing knowledge is endlessly long and these are strongly oriented to cultural and ideological values (e.g. religions, cultural values). Redundancy in the sense of widely scattered deposition of information at geographically different locations can reduce the risk of information loss through the destruction of archives (Weitzberg 1982). Other risks involving information loss or distortion that should not be underestimated are copying problems with respect to the media used (e.g. electronic data processing) and the information content itself. The potential for interpreting and manipulating information has always been large as evidenced by numerous historical examples (see e.g. Assmann 2007). However, technical installations are less affected by this than ideological and religious works (see E3 and E4).

Appraisal

Greater attention should be paid to the problem of distortion of information over time. The most important point in this respect is the realisation that underground marking has to be very accurate and considered from many perspectives. This problem remains virtually untreated in the literature, partly because marking concepts to date have been concerned mainly with surface facilities.

Surface marking is exposed to environmental influences and social change. Maintenance, repair and rebuilding are therefore key elements if marking at the surface is to remain intact over a time period of 10,000 years.

The conceptual design of an underground marking system has to be well thought out and very advanced before it is implemented.

E3 What requirements apply to the decoding of marking and trading systems (information media, structural requirements, encoding and decoding systems, etc.)? How large is the potential for misinterpreting marking? Can marking present a hazard to a deep repository? In other words, can marking lead to a repository being deliberately emptied?

Problem definition

The long time period between encoding and decoding of messages makes storing information imperative. Major cultural changes are expected over such timescales. In the best possible case, the repository will still be located in the same cultural domain, meaning that cultural roots will be maintained and the key requirements for decoding messages (such as language and script) will be the same. In the worst case, there will be a fundamental cultural disruption with loss or complete overprinting of cultural identity, meaning that the requirements for decoding messages may no longer be met. Historically, such deep-reaching disruptions with loss of cultural identity have been seen in ancient cultures (Hittites, Mesopotamian cultures, Egypt of the Pharaohs, etc.). These change processes place extremely high demands on the encoders and the recipients of the message.

Information in the literature

The principle of changes in values and culture was recognised in the earliest works on marking (Kaplan 1982, HITF 1984, Sebeok 1984) and guided the concepts for how information could be

transferred over time. Having recourse to the theoretical principles of information transfer is an important basis for identifying and evaluating the risks of error propagation. Sprenger (2007, p. 42-52) applied these principles (Shannon flow diagram; semiotics of Sebeok) to the problem of nuclear waste disposal. The two major problems that presumably arise in information transfer are the contextual framework and the channel through which the message will be transferred. If one looks at history, the contextual frameworks for the composers of a message and the recipients are likely to be fundamentally different, meaning that there is a significant potential for misinterpretation by the recipient. Particular attention has to be paid to changes in messages over time and changes in the symbols used in a message. The transmission of messages and the use of character codes are subject, on the one hand, to the “noise” of time, but also to concrete erosion and disruption processes. History provides us with impressive examples of such incidents: papyrus scrolls from Nag Hammadi were used to make fire and destroyed; writings of philosophers and religious leaders such as Epicure or Mani that were considered to be dangerous underwent radical elimination by the Christian church (see E4). Much that was usable, including written and thus encoded material of ancient provenance, was removed by newer cultures and thus denied to potential recipients.

The list of potential perturbations is long and includes changes in social conventions. Sebeok (1990, p. 150 ff.) shows how conventions are dependent on context: a raised hand with the thumb and forefinger making a closed circle can have very different meanings, from OK (USA) to zero (France), to money (Japan), to an obscene insult in ancient Greece (Sebeok 1990, p. 1947). A similar change in understanding can also be expected for iconic representations, warning signs or written messages (Sebeok 1990, p. 156). When decoding instructions, false interpretations are almost pre-programmed as different cultural backgrounds have different priorities (Givens 1990, p. 108). Language is also no guarantee for error-free transmission: based on a statistical analysis of the change in English vocabulary, it was calculated that, after 10,000 years, only around 12% of the basic vocabulary will still exist (Posner 1990b, p. 47). Other sources of error include misunderstanding (Sprenger 2007, p. 6), declining a message (Sprenger 2007, p. 7), disruption of the sequence of relocation, storage and restoration of information (Sprenger 2007, p. 10), loss of social cohesion and social change (Sprenger 2007, p. 9). Sprenger (2007, p. 58) also raises an interesting question: what happens when the all-clear for the risk in question could be given but the marking system continues on?

Appraisal

The future is open – the most incisive realisation for any social system. It can never be ruled out that there will be a misunderstanding of marking and the information left behind. The more widespread a culture and its language are, the better the chances are that information from a marking programme can be correctly interpreted at least to some extent. The potential for misinterpretation grows with the erosion of key cultural attributes. If the marking system is still intact after the radioactive hazard from the repository has largely decayed away, this is not particularly relevant. The repository can be drilled into or cleared out without any grave consequences.

E4 Are the relay structures for long-term transfer of information²⁵ sufficiently secured against erosion and falsification processes? Can manipulation of such structures be prevented?

Problem definition

As every lexicon of natural and human sciences shows, knowledge and technology have developed enormously over the last thousands of years. With the Industrial Revolution, a scientific and technical process was put in motion and its evolution and end are not yet in sight. This process goes hand in hand with huge social change, both in terms of the economic boundary conditions of a society and the associated changes in values and culture. The revolution in the information society marks attempts to communicate with the future. However, the risks for static facilities such as deep repositories also increase with these technical developments.

²⁵ See discussions in D2, D4, A2 and the Glossary.

Information in the literature

Up till now, the focus of the topic of manipulation was on the role of a powerful institution that would take over the role of passing on information over a period up to 10,000 years (Weinberg 1999; Sebeok 1990, see O3 and D4). This led to often bitter discussions of the role and power structure of such an “atomic priesthood”. The opinions of the proponents of a strong lead institution (atomic priesthood, long-term stewardship) converged with those who support religiously or morally and spiritually based structures (nuclear guardianship, cf. Garfield n.d.; www.rmpjc.org/about+Nuclear+Guardianship). The criticism of these approaches stressed the blandness of the ideas and the ambiguity of the content of such priesthoods and referred to the strong dependence of such structures on the social structure of the present day (Blonsky 1990, p. 176, 182; Buser 1998, p. 50–53).

In the literature considered, there is more or less a consensus that information about deep repositories should be passed on to future generations. What is not clear is the structural framework that should be created to ensure that the transfer of information is as “loss-free” as possible. The IAEA (1995, p. 5 ff.; 2006, p. 14 ff.) defines certain principles that should be considered as guidelines for the organisation and management of such a task, underlining the fact that national legal regulations, governmental responsibility and independent regulatory control are essential. If information transfer has to be assured over long times, the responsibilities have to be maintained constantly in a future relay system.

Appraisal

The need to accompany a repository in the future with an organisation with long-term character is fundamentally recognised today (see D4), but the risks associated with such a structure have not really been addressed in the literature. Organisational sociology – the area into which such questions fall – has problems with issues of this type. The susceptibility to perturbation of a long-term relay system, its durability in times of crisis and its resistance to manipulation attempts are real threats that have to be taken seriously at an early stage.

A number of fundamental weaknesses and risks associated with relay systems were represented by George Orwell in his novel “1984” by a society that continually corrected and re-wrote history. Orwell’s criticism was aimed at the communist system and its philosophical foundation, historical materialism. With his criticism, Orwell also revealed two weaknesses in the handling of information by centrally managed institutions: the absolute control over information and the power to change information to suit one’s own purposes. Other structural weak-points and risks in a long-term relay system can be recognised today, for example deficits in structural modification: as present-day structural modifications show, organisational structures are continually reviewed and re-configured. The likelihood that important tasks that are essential for maintaining security or safety over long time periods will be distorted or lost in the various stations of a relay system is very large. Each restructuring process means changes in organisations and procedures and, to some extent, new objectives and divisions of responsibilities. A direct consequence of such structural modifications is a higher susceptibility of the transmitter to perturbation (see Figure 4.1b), e.g. a relay station could decide to “dilute” the information on the repository and only transmit information considered to be essential; conversely, a relay station could also attempt to re-interpret information. Key information could thus be falsified or over-interpreted or, in the worst case, could even be lost, as many historical examples show (Bendikowski et al. 2003; Fried 2004). Added to this are the risks that arise from a system that initially functions well: slackness in monitoring, routine, laziness of the responsible information-bearers, etc. There is also the risk of deliberate manipulation, either to conceal errors, to meet requirements that are difficult to fulfill or simply for the sake of convenience (see e.g. the recent debates in Germany on the Asse and Gorleben repositories). Finally, mention should also be made of the considerable risk of information loss in the case of serious system crises with structural reforms. As this brief overview of possible sources of error shows, the susceptibility to perturbation of a long-term relay system is much greater, but these issues are rarely addressed in the literature.

	Structural marking technologies	Purpose	Demonstrated durability	Risk scenarios	Requirements on marking
1	Structures at the surface	Marking the surface above the repository as a place of warning and memorial	Maintained: up to > 2000 years (Pont du Gard, Pantheon Rome, Porta nigra Trier, etc.) Not maintained: < 250 years	Recovery of valuable resources (e.g. hewn stone, tiles)	No monumental structures, no use of hewn stone, walls from worthless material
2	Structures beneath the surface	Duplicate of disposal chambers (info repository) at or beneath the surface for future archaeologists	Maintained: up to > 2000 years (Catacombs Rome, Eupalinus water tunnel, Pythagorion Samos, etc.) Not maintained: < 250 years, exceptions up to > 2000 years Asphalt sealing up to > 2000 years	Collapse due to lack of maintenance	Stable walls from worthless material, careful implementation of seals, etc.
3	Objects buried beneath the surface (< 2 m)	Warning signals	Rock/silex: > 1 million years Terracotta: > 10,000 years Glass: 1000s of years Metal: < 1000 years (except native metals)	Interest in antique objects	Unattractive, identical objects (e.g. terracotta, special ceramics) in very large volumes with identical warnings and measures (warning or radio tokens)
4	Marking objects in the shaft area and access galleries (e.g. circular galleries)	Control function for dismantling, warning function	Special ceramics/terracotta: > 10,000 years Glass: 1000s of years Other materials (metals): < 1000 years (except native metals)	Interest in antique objects	Unattractive, identical objects (e.g. special ceramics) in very large volumes (e.g. annular marking with radio tokens every 2 m) with identical warnings and measures
5	Disposal chambers or tunnels (according to concept)	Control function for dismantling, warning function	Special ceramics/terracotta: > 10,000 years Glass: 1000s of years Other materials (metals): < 1000 years (except native metals)	Interest in antique objects	Identical to marking objects in shaft area, designed specifically for emplacement technology
6	Disposal containers and possibly reflectors	Warning function	Steel container: < 10,000 years? Copper container: > 100,000 years? Other materials: ?	Interest in resources / recovery of valuable materials	Making the disposal containers from special ceramics or other worthless material
7	Chemical markers	Warning function	Unknown	Interest in resources unlikely	Clarification of durability, manufacturing of chemical warning markers

Table 4.3: Marking technologies from the perspective of long-term risk consideration. The more unattractive the marking system, the more likely it is to remain intact over long times. A number of materials proposed for marking in the waste disposal zone (rubber mats, rubble; see e.g. Tolan 1993, NST 2007) are rejected in this study for reasons of safety

4.4 To mark or not to mark?

Important conclusions from the analyses to date

What is clear from a study of the literature on marking is the high level of detail of the proposals as to how marking in its widest sense can be assured for future generations. In this respect, it is important to recognise that the technical possibilities for such undertakings have been widely discussed and are continually updated, even if this is not always done as part of truly systematic analyses. Despite certain shortcomings, research and development appears to be on the right track.

What is also clear is that the question of what is ultimately to be “marked” has not been posed or answered with any clarity. In other words, in many cases the object that presents the danger tends to be forgotten. In these marking studies, the repository is seldom specified in terms of its content, meaning that one of the key questions that is found repeatedly in archaeological and historical studies is moved into the background, namely why a society or individual interest groups or individuals do or do not do something. The potential answers to this question could contribute to making the purpose of marking more apparent and to developing possible strategies for implementing marking programmes.

As shown by risk scenarios for intrusion into a future repository (Table 4.2), there is no clear answer to the question whether future generations will find the marking of a repository meaningful or not. In some cases, it will prove to be meaningful and in others it will not. What should be borne in mind in further consideration of the marking issue in the case of deep repositories is the knowledge derived from thousands of years of human culture and technology. Socially widespread human attitudes should be kept in mind in the planning of repositories and potential marking programmes (see also Table 4.3):

- Whatever we think or do, we cannot take away from future generations the power to make decisions about the future or enforce these decisions on them. Social values are closely bound to the body of thought of a particular time and can only be transported beyond this to a very restricted extent. Information media also change with time, as evidenced by changes in language. For marking programmes, this means an unpredictable potential change in future decoding of information encoded by us, but also possible reuse of the materials. The randomness of this – what remains preserved and what not – can be seen in the example of the clay tablet archives in Mesopotamia that were often exposed to fire during conquests and became ceramicised and thus remained intact (McCall 1993, p. 38; see cuneiform script tablets from Qatna, Syria).
- If materials or objects can be reused or recycled, future generations will tend to do this, as numerous historical examples have shown (see e.g. spolia, Poeschke 1996, Buser 2013). Examples include reusing building components²⁶ or metals²⁷. An impressive example of this phenomenon comes to us in the form of the main mosque of Kairouan from Guy de Maupassant on the occasion of his travels in Tunisia in 1889²⁸. This knowledge should be

²⁶ For example, the mosque in Cordoba (Spain), the Mértola mosque (Portugal), the cathedral in Pisa (Italy), the Cluny stables (France), the Kairouan (Kirwan) mosque (Tunisia), etc.

²⁷ From Etruscan-Roman slags in the Gulf of Baratti to modern use of slags from waste incineration facilities, cf. www.bafu.admin.ch.

²⁸ “In the entire world, I know of only three religious buildings that have left such a surprising and overwhelming impression on me as this barbaric, intriguing building: the Mont-Saint-Michel, San Marco in Venice and the Palatine Chapel in Palermo [...] Here it is completely different: a roaming population of fanatics barely capable of building walls arrives in a land covered in the ruins of their predecessors, carry everything they consider to be most beautiful here and – driven by a sublime inspiration – build a house for their God from the rubble, a house

kept in mind by repository planners when assessing the risk of intrusion in the future. Marking in the form of large structures could fall victim to the construction projects of future generations (figures 4.6 and 4.7). Clay shards or small clay objects have a better chance of survival, for example tokens or bulls, of which large numbers have been found in Mesopotamia (Schmandt-Besserat 1996, Watson 2005, McCall 1993, cf. figure 4.3). Tokens were used as counters and their use was widespread.

In contrast to clay, metal objects have been preserved on a much smaller scale because they are relatively easy to recycle (according to tradition, even the Colossus of Rhodes, which collapsed during an earthquake, was recycled) or because they have corroded away. The worthlessness of an object, the durability of a material against weathering or chemical attack and its non-universal use are the main preconditions for preservation of the transmitted information. The more unattractive a place is, the greater the likelihood is that it will remain intact over time.

made of fragments taken from crumbling cities that is as complete and magnificent as the purest creations of the greatest stonemasons." Guy de Maupassant: *On route to Kairouan, North African Impressions*. From the travelogue "La vie errante", selected by Erik Maschat, E. Piper & Co. Verlag, Munich 1957; www.de.wikipedia.org/wiki/Kairouan.

Buildings and infrastructures in the ancient world: categorisation based on their symbolic value and / or their ideological character

Building with symbolic character	Cultural monuments	Military infrastructures	Administrative infrastructures	Other infrastructures	Production and resources	Other
Temples	Theatres	Defensive structures Walls Towers Trenches Fortifications etc. Castles Others	Palaces	Ports	Mines (Ores)	Baths
Museums			Administrative buildings	Lighthouses	Quarries	Villas
	Amphitheatres		Bridges	Forges	Marketplaces	
	Arenas		Roads	Ovens (smelting)	Other buildings	
	Stadiums		Aqueducts	Shipyards	Others	
Necropolis			Dams	Others		
Mausoleums			Sewers			
Monuments (reliefs, steles, arches of triumph etc.)				Reservoirs		
Libraries				Others		

Buildings with high symbolic value (Religious symbols and archives)
 Buildings with moderate symbolic (moral) value (Buildings, sports, cultural and recreational facilities)
 Building without special symbolic value (Economy and infrastructure)



Figure 4.6: Symbolic value, vulnerability of buildings to be potentially reused in the future and examples of the reuse of ancient building materials (spoliae, photos: peninsula of Mani, Pelopponese, Greece, Peter Schait, Zürich)



Left to right: examples of dolmen transformed into Christian chapel (Anta of São Brissos, Santiago do Escoural, [photo M. Buser] and Anta of São Dinis, Pavia [Photo Cornelius Holtorf], both in the district of Evora, Portugal, romanesque church transformed into a farmhouse near Cluny, France [photo R. Zurbuchen]).

Reasons for the destruction or re-use of old buildings and infrastructure

Reasons for destruction or re-use	Buildings with high symbolic value	Buildings with moderate symbolic value	Building without special symbolic value
Social and political events <ul style="list-style-type: none"> • Wars • Revolutions • Crises • Terror 	Religious and cultural buildings, libraries	Military and administrative infrastructures	Infrastructures Production structures
Economic and technical events <ul style="list-style-type: none"> • Reuse of buildings (e.g. quarries) • Loss of interest in older infrastructure (new techniques available) • Replacement of older techniques 	Religious and cultural buildings	Military and administrative infrastructures	Infrastructures Productions structures
Natural events <ul style="list-style-type: none"> • Earthquake • Volcanoes • Other (floods, transgressions etc.) 	Damage high for all type of buildings and infrastructures in high risk areas Otherwise damage moderate to small		

 High destruction or damage ratio

 Moderate destruction or damage ratio

 Small destruction or damage ratio



Figure 4.7: Reasons for the destruction or later re-use of buildings and some examples of frequently performed later transformation of temples through history (to the right: the former muezzin-tower [Giralda] of the later cathedral of Sevilla, photo Marcos Buser))

These findings should be considered by those planning repositories and implementing marking strategies, particularly at the time when implementation of a marking programme in terms of content and technical aspects is imminent.

- Recycling is not restricted to material goods. Art objects, art and ideas can also be used and changed over time. The development of the written word in ancient times is an example of the process of the exploitation and reuse of old writing systems (Haarmann 2002, 2006). In a similar way, the recycling of ideas (Watson 2005) and also of religious content (see Eliade 1978) can also be evidenced. The interpretation of observations and ideas is also subject to change, as shown by the development of science or ideas from a constructivist or de-constructivist viewpoint. Semioticians draw attention to this particular aspect in the context of disposal of radioactive waste when they refer to changes in the contextual framework. When planning repositories, it should be kept in mind that it is not only the technical disciplines that are of key importance in the development and marking of these facilities. The awareness that no cultural system conceived or developed by man is “set in stone” is also important. History is what we remember, what remains in the collective memory (see Assmann 2007, p. 34).
- Despite all the crises, the evolutionary history of mankind has always proceeded in one direction. In the process, cultures, cultural objects and languages have been eliminated, but “victorious” cultures always develop new impulses, which ultimately lead to a renewal of technology. During the Middle Ages in Europe, research in monasteries began to develop and was moulded through colonial history and the subsequent Enlightenment into a tool that is unique in the history of humankind. It is difficult to imagine that such a huge body of knowledge in the interconnected world that we live in could be completely wiped out by a global catastrophe. Whatever happens: the capacity of man for abstraction and logic suggests that, even after a time of extreme crisis, societies will be in a position to find repositories through targeted exploration, even if they have been forgotten for long periods of time. The question is not so much whether to mark or not to mark, but rather to whom and where a marking programme should be oriented.
- Finally, mention should be made once more of the peculiarities of communication over time. The exchange and transmission of information and values through time has always been accompanied in the historical process by distortions and falsifications of the object of the information. The semiotic model has rightly assigned an important role to information transfer between encoding and decoding, assigning it not only a technical transfer component but also an important social function (Verón 2004, p. 134 ff.). The creation of information and its absorption are processes that are driven by subjective components where ideology and power play a key role. Only in this way can it be explained how information transfer can be significantly altered or falsified through chains of information bearers.

5. Conclusions

The present literature study focuses on the questions relating to marking in a fundamental and systematic way. Consideration of the status of knowledge on the issue of marking shows that, with reasonable effort, a wealth of information can be derived from the available literature. Of course, a more extensive consideration of the literature would provide additional knowledge and would give a clearer and more detailed picture of what marking can and cannot do. Even with a more extensive analysis of the topic, fundamental questions should no longer arise. This is shown by the findings in this study which, in many aspects, draw on the extensive studies carried out in the 1980s and 1990s. However, some new information has been identified and marking studies have been put in a wider technical and social context. The following findings seem to be particularly important or interesting:

- **The need for syntheses:** It is important to stress the need for syntheses. They allow a problem to be looked at in its entirety by bringing together information in a particular area and organising and concentrating it. Syntheses also highlight the problems and contradictions in the area of knowledge under consideration and allow the level of knowledge and concrete project developments to be monitored periodically. New perspectives and values can be integrated into syntheses so that, if necessary, corrections can be made in concrete projects. The benefit of periodic reviews is generally acknowledged.
- **Inconsistency:** The objectives of marking and concrete implementation strategies for projects are not free of inconsistencies. Where marking is carried out, a “fingerprint” is left behind; where there is no marking of a repository, this fingerprint is more difficult to identify. However, modern technology would allow the access structures to a carefully concealed repository to be found without too much difficulty (e.g. aerial archaeological imaging, using georadar for surface structures such as approaches to shafts and ramps). Inconsistencies arise in connection with some concrete points of marking and cannot be completely eliminated. However, developments in a system that occur independently of the project also have to be taken into consideration (see below).
- **Comprehensiveness:** The overall consideration of a concept – whether surface marking or not – should be done consistently and should include all technical and non-technical factors. Technical disciplines have to open themselves up to the interests of semiotics and knowledge from archaeology and history. Conversely, the planning of marking strategies also has to include consideration of technical issues such as corrosion and gas formation. To give an example, the installation of large magnetic iron markers in a deep repository has to be rejected because of potential problems with corrosion and gas formation. An overall approach should ensure that potential interactions between individual components of the marking system, the safety system and the different technical disciplines can be recognised and evaluated.

- Systemic development²⁹: The development of human society is closely coupled to changes in living environment. Developments in a specific group are taken over by other groups and, in this way, are rapidly propagated. Technology provides many examples of this, beginning with the production of silex tools in the Stone Age through the megalithic culture of the New Stone Age, the construction of Roman and later Gothic churches to electrification and development of railways, cars, planes and computers. For repositories, it is foreseen that there will be a tendency to implement similar marking strategies. An individual project is unlikely to go completely against the general trend of development.

Finally, it is important to note that communication over time requires special conditions to be fulfilled. For transferring knowledge of a repository over long times and formal configuration using semiotic technologies and objects, these requirements are of a particular nature. Semiotics has identified the potential for misinterpretation of information on a repository through conventional character sets. The fact that the discourse on disposal is already marked by ideology and reflects power positions only highlights the challenge of semiotic mastering of marking programmes.

In this sense, the approach of trading the topic of radioactive waste through mythical tales could – despite all the criticism³⁰ - be interesting, as the core of the message can be packaged in stories that deal with more fundamental existential themes (creation, death, size, freedom, etc.) and less with daily political or ideological topics. All the great myths of the peoples of this earth have had a huge impression over time, from ancient Babylonian myths such as Gilgamesch and the Atrahasis, the biblical story of creation, myths from the Middle Ages such as the Holy Grail to the modern myths of nations such as William Tell or Joan of Arc – all tales of heroes with classical power and charisma.

²⁹ Systemic: see glossary

³⁰ See Blonsky (1990, p. 169ff.), Sprenger (2007, p. 60 ff.).

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Glossary of key terms used in the text

AGNEB	Swiss Federal Workgroup for Nuclear Waste Disposal
Algorithm	An effective method expressed as a finite list of well-defined instructions for calculating a function
Analogue	Item which, in a historical context, provides information on past physical, chemical and biological processes. Analogues are based on the actualism principle of James Hutton and Charles Lyell, which states that all present-day processes also operated in the past, making historical interpretation and reconstruction possible
Channel	Central concept within semiosis that expresses how symbols of a message can be transmitted. The channel expresses the ability of a pathway to transport information
Chiliasm	See Millenarianism
Code	Instruction for encoding a message in symbols
Constructivism	Collective term for scientific and artistic theories that assume that knowledge and meaning are generated from an interaction between human experiences and ideas and do not reflect a generally valid truth
Context	Environmental conditions, key term for characterisation of semiosis
Cuneiform script	Cuneiform documents were written on clay tablets, using a blunt reed as a stylus. The impressions left by the stylus were wedge-shaped, thus giving rise to the name cuneiform ("wedge-shaped", from the Latin <i>cuneus</i> , meaning "wedge"). Best known in Mesopotamia
Decoding	Deciphering of a (symbol) message
Deconstruction	A term coined by French philosopher Jacques Derrida to identify a method for interpreting works
Denudation	Removal of land surface area; erosion follows a linear pattern (e.g. rivers, valleys)
Durability	Term for the stability of a carrier material (medium) against physical, chemical and biological degradation
EKRA	Expert group on disposal concepts for radioactive waste set up by the Swiss Federal Department of the Environment, Traffic, Energy and Communications (1999-2001)
Encoding	Encryption of a (symbol) message
EPA	Environmental Protection Agency. An independent authority of the USA for protection of the environment and human health

Eschatology	Catholic doctrine of the purposefulness of divine creation, used particularly in connection with the end of the world or humankind and the beginning of the Second Coming
Exhumation	Opening of a deep repository (see human intrusion or retrievability); originally used for removal of a buried corpse
Fluvio-terrestrial	Of an area defined by the radius of influence of a river. The term comes from sedimentology and is the opposite of marine, namely sediments deposited in a marine environment
Geomorphology	The scientific study of landforms and the processes that shape them
Georadar	A technique for investigating the underground environment using electromagnetic impulses. Georadar campaigns are generally restricted to the first 10 metres of the underground
Hermeneutics	Study of the theory and practice of interpretation
Hieroglyphs	Engraved symbols; term used in connection with the Egyptian script that used symbols originally considered as holy (“hieros”)
Human intrusion	Umbrella term for intentional or unintentional penetration into a repository after it has been closed; not to be confused with retrievability
Hydrosphere	The combined mass of water found on, under, and over the surface of a planet
IAEA	International Atomic Energy Agency. Autonomous agency of the United Nations that works for safe and peaceful use of nuclear energy
Icon	Symbol in semiosis or abstract pictorial or tonal symbol that creates a link to a certain object; see also pictogram
Ideogram	Graphic symbol that represents an idea or concept, e.g. ‘?’ for question mark or ‘\$’ for dollar
Lithosphere	The outer solid part of the earth
Marker	Term for objects placed along boundaries to designate an area of influence, power or danger
Marking	Collective terms for a project for delineating an area
Medium	Basic material on which marking is introduced, e.g. clay, glass, rock
Millenarianism	In Christian culture, the belief in the Second Coming of Christ according to the prophecy of John; often used together with eschatological messianism and the end of the world and the Day of Judgment after a thousand-year reign of evil. The entire history of Christianity, particularly the Middle Ages, was strongly influenced by this milleniaristic world experience. Jewish and Islamic traditions also acknowledge millenarianism. Reference should be made to key works for an understanding of the content and history of eschatology and millenarianism

NEA	Nuclear Energy Agency. Semi-autonomous institution within the OECD for promoting safe, environmentally sound and economic use of nuclear energy
Neolithic	Revolutionary evolution of the culture of Homo sapiens at the transition from the middle to recent Stone Age around 10,000 years ago (transition from hunter-gatherer to settled populations)
Pictogram	Symbol that provides information via a pictorial representation
Relay	Relay chain, relay station and similar terms are used to characterise transfer functions. A relay point is a specific point in a time-chain at which information is reprocessed and passed on to the next generation. The purpose of relay systems is the renewal and passing-on of information and should minimize loss of information over time
Retrieval	Deliberate re-opening of a repository for the purpose of removing already emplaced waste; not to be confused with human intrusion
Rotary drilling	Drilling technique originally developed in the petroleum and natural gas branch that is now widely used for underground investigation. The rotating drill-bit penetrates the rock by fragmenting it. The drill cuttings are flushed out in suspension
Run-off	Surface drainage (precipitation, snow and glacier melt)
Semiosis	General model for information transfer over time that investigates the relationships between the information source and the recipient of the information. Information transfer is by symbols, object (item to which a symbol relates) and meaning of the symbol. Semiosis is a flexible term; in recent interpretations it also includes the context or boundary conditions under which information is transferred
Spindletop	First oil borehole drilled with rotary technology in Beaumont, Texas
Stakeholder	Person involved in, or affected by, a process
Synthesis	Summarising and compaction of information considered to be important and that provides an overview of an area and its associated problems
Systemic	Term derived from the noun "system" that is used in many technical disciplines when reference is made to complexity and change within a specific system
Toponym	Name of a location (place and area)
Trading	Transfer and passing on of cultural values (beliefs, values and actions) between generations
Transmitter	One responsible for the task of transferring information
Transmutation	Science and technology of the alteration of fissile nuclear elements into less long-lived elements
WIPP	Waste Isolation Pilot Plant (deep repository for military radioactive waste) at Carlsbad, New Mexico (USA)