

## Planning to ‘remember to forget’?

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### ABSTRACT

Disposal in deep geological formations aims to provide isolation of long-lived radioactive waste for hundreds of thousands of years. This raises the question of the long-term governance of the repository throughout its lifetime. In the operational phase the repository is under active regulatory control. Once closed, there will be a phase of passive management control or indirect oversight. This will be followed, at some time in the future, by a period in which there is no oversight. This may be a result of a decision to cease management control or it may occur through loss of records or a change in priorities. The importance of the main exposure scenarios (exposure as a result of the gradual transport of radionuclides in groundwater, transport of radionuclides in gas, and exposure arising from inadvertent intrusion into the repository) are discussed with reference to these different phases. An interesting question is ‘How do we minimize the risk of inadvertent intrusion in the far future?’ Perhaps it is better to ensure that the repository is forgotten and should we try to plan for this? The different approaches are discussed and the importance of deciding on a strategy at an early stage is emphasized.

**KEYWORDS:** geological disposal, long-term safety, radioactive waste.

### Introduction

DISPOSAL in deep geological formations has been proposed as a waste management option for long-lived radioactive waste for many years (SKB, 1983; Commission of the European Communities, 1988; UK Government and the devolved administrations, 2006) and is currently under research and development in a number of countries.

Worldwide, there is general agreement that the only viable long term strategy for the storage and/or disposal of high level/heat-generating waste (including spent reactor fuel) is in deep geological formations. Current activities in most countries are focussed on the development of strategies for site selection, the development of repository and near field engineering solutions (e.g. packaging, geological and man-made barriers) and safety assessment of geological repositories. Several

countries have constructed underground test and research facilities (e.g. Sweden, Finland and France). However, to date there are no operating deep geological repositories for heat-generating wastes such as high-level waste or spent reactor fuel; the Waste Isolation Pilot Plant (WIPP) in the USA accepts long-lived transuranic (TRU) wastes with some heat output, but does not accept high-level waste from the civil nuclear power industry.

Disposal is generally defined as the emplacement of radioactive waste without the intention of retrieval, and without reliance on long-term surveillance and maintenance. Geological disposal (i.e. disposal in geological formations at distances from the surface of hundreds of metres) is also currently recognized by international organizations (Organisation for Economic Co-operation and Development – Nuclear Energy Agency, 2008) with responsibilities for radioactive waste management as especially suited for high-level radioactive waste or spent fuel, where long-term containment is required. Geological disposal may also be used for other wastes

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TABLE 1. Indicative order of magnitude timescales of past and future events.

Years (order of magnitude)	Historical event	Possible future event	Radionuclide half-life
100	Radioactivity discovered	Greenhouse effects	$^{14}\text{C}$
1000	Norman invasion (1066) Pyramids (4600 BP) Man-made glass (5000 BP)	Ecological changes. Mineral and many energy sources exhausted?	
10,000	Agriculture starts First pottery (18,000 BP) Last glaciation (22,000 BP)	Local ice advance in Scandinavia?	$^{239}\text{Pu}$
100,000	Modern humans appear (200,000 BP) Neanderthal man appears (500,000 BP)	Time between glaciations	$^{99}\text{Tc}$
1,000,000	Humans branch from apes (5,000,000 BP)	Deep geological formations generally unchanged	$^{237}\text{Np}$
10,000,000	Dinosaurs extinct (K-Pg event 65,000,000 BP)	New species evolve? Movement of continents	$^{129}\text{I}$
100,000,000	Dinosaurs	Large meteorite strike Sun becomes red giant	$^{238}\text{U}$
1,000,000,000	Multicellular organisms Age of the earth		

containing long-lived radionuclides, since similar long-term protection requirements can be formulated. An example of geological disposal is the emplacement of waste in excavated tunnels or shafts, followed by backfilling and sealing of the entire facility.

The goal of a geological disposal facility is to achieve the isolation and containment of the waste and to protect humans and the environment for timescales that are comparable with geological changes. At great distance from the surface, such changes are particularly slow and the radioactivity of the emplaced wastes will gradually reduce over time. Additionally, if a site is chosen in an area with no obviously useful natural resources, the potential for human intrusion will be limited. Finally, a properly chosen geological formation would assure stable chemical conditions for the waste and would attenuate and slow down any transport of radionuclides to the accessible environment.

The safety strategy implemented for geological disposal is to concentrate and retain the waste. The disposal facility is therefore designed to isolate and contain the waste over as long a period of time as possible, with controls that are in-built, and to ensure that the safety of the facility, after facility closure, does not rely on the presence of man.

It is difficult to appreciate the timescales that are considered in radiological assessments of geological repositories. Table 1 gives an order of magnitude indication of the timescales of some past and future processes and also gives the half-lives of some of the radionuclides that are likely to be present in the wastes. This table helps to give some context to the concept of a dose that is estimated to occur in thousands or millions of years.

The very long timescales mean that there are uncertainties with regard to the protection standards that will apply in the far future. Since it is not possible to predict what standards will apply in the future, the basic philosophy is to protect future generations to the standards that are acceptable today.

There are also uncertainties associated with the long-term evolution of the facility (e.g. in relation to the mechanical stability of the underground openings). Normal and predictable phenomena are likely to be mitigated by the inherent properties of the facility and its environment. Other phenomena (e.g. severe disruptive events or inadvertent human intrusion) that may or may not actually occur, require separate assessment and consideration. In particular, if inadvertent intrusion does occur the consequences for the intruder might be high. This is an inescapable consequence

of the decision to concentrate waste in a disposal facility. It is therefore important to consider both the migration and inadvertent intrusion exposure scenarios when performing a radiological assessment of the facility as part of a safety case. The extent to which the inadvertent intrusion scenario should be planned for in the repository design is discussed further in this paper.

### Inadvertent intrusion

Intrusion can be divided into two main types: intentional intrusion and inadvertent intrusion. Intentional intrusion (i.e. deliberate intrusion into a facility with full knowledge of its presence and contents) will be planned and managed by those undertaking the action. This type of intrusion does not need to be considered when performing a radiological assessment of the repository because it is widely accepted that current society cannot protect future generations from their own actions if they are aware of the consequences. For example, if the actions are intended to retrieve the waste the resulting doses will be controlled; if the actions are intended to deliberately compromise the safety of the facility the consequences for the intruder are their responsibility and existing procedures for dealing with such events (such as terrorist attacks) would come into play.

Inadvertent intrusion (i.e. human actions that may in themselves be intentional but are done without full knowledge of the location and understanding of the contents of the disposal facility) need to be considered. For example, it might be known that human activity had taken part at the site but the radioactive nature of the contents of the facility might not be known. Examples of inadvertent intrusion that could happen are archaeological investigations and exploratory drilling for resources or scientific purposes. These actions should be considered in a radiological assessment of the repository.

### Evolution of a repository

It is useful to consider the timeline of a geological disposal facility. The International Commission on Radiological Protection (ICRP), in their recent consultative document on geological disposal (International Commission on Radiological Protection, 2011), identifies the three main phases of a repository to be the pre-operational phase, the operational phase and the post-operational phase. However, ICRP point out that

an important aspect with respect to the radiological aspects of the safety case for the repository is the degree of oversight ('watchful care') or regulatory control of the site that is in place. The implications of the degree of oversight are considered below.

#### *Direct oversight*

In the pre-operational and operational phases there will be direct regulatory oversight. Therefore any releases will be planned, and the resulting doses to operators and the public will be controlled. The radiological impact of any accidents or natural disruptive events (such as floods) will also be managed according to the radiological protection criteria prevailing at the time. Most importantly, there will be no inadvertent human intrusion. This period of direct oversight may last several decades, covering the construction of the facility, emplacement of radioactive waste, and the backfilling and closure of the geological disposal facility.

#### *Indirect oversight*

Once the facility has been backfilled and closed there will be a period of active care and maintenance of the facility by monitoring, surveillance and remedial work. This period may last for several decades or more. It is not reasonable to assume that active care and maintenance will continue forever, and therefore it is assumed that active regulatory control of the site will cease at some point in the far future. This may be the result of a review of the hazard potential of the site, or as a result of changed priorities or lack of resources, or even the collapse of civilization. At this point archives containing records of technical data and the configuration of the disposal facility will remind future generations of the presence and purpose of the facility. Markers may also be used to indicate the location of the facility. Any expected releases to the public will be monitored and controlled and the impact of any accidents or natural disruptive events will be managed and controlled to meet the current standards. Inadvertent intrusion will not occur.

#### *No oversight*

It is not reasonable to assume that the records and markers will continue to be effective forever, and therefore a period of no oversight should be

considered in the design and planning stage of the facility. This is important because inadvertent human intrusion cannot be ruled out if there is no oversight of the facility. It should be noted that during the period of no oversight, the repository is still performing its safety function (isolating and containing the waste), and although the intrinsic hazard will be reducing over time through radioactive decay, the waste may still present a significant hazard if inadvertent intrusion occurs. Releases to the environment as a result of transport in groundwater and gas are expected to meet (current) regulatory standards and therefore would not require any remedial actions. However, for disruptive natural events and inadvertent intrusion the situation is different. No action would be taken until the radiological aspects of the event had been recognized; as soon as they were, regulatory control would commence and the radiological protection standards applicable at that time would be applied to control doses. There is the possibility that the radiological aspects of the event would not be recognized for a long time, or even at all.

### Protection against inadvertent intrusion

Radiological protection aims to protect people from the harmful effects of ionizing radiation. The ICRP define three basic principles: justification, optimization and dose limits, that should be applied to radiation sources. The justification principle applies to the entire practice producing the doses and hence applies to the generation of nuclear power and the associated waste disposal facilities as a whole, and not to geological disposal in isolation. Dose limits are addressed by setting appropriate dose constraints for a single practice and therefore the main principle to apply is optimization, respecting the dose constraints. Optimization involves demonstrating that the estimated doses are below the appropriate dose constraints and that as much as is reasonably possible has been done to reduce doses, taking other factors into account.

Optimization for inadvertent intrusion could address two aspects: reduce the dose if it occurs and reduce the probability of occurrence. However, there is nothing that can be done to reduce the dose, if it occurs, since international policy does not permit the dilution of high-level waste to produce less hazardous waste. Hence the only approach is to reduce the probability of occurrence. This has already been done by

choosing deep geological disposal as the option and by placing the waste at depth. The role of optimization is therefore to look at any options for further reducing the probability of inadvertent intrusion and to determine the benefits and disadvantages of each of these options; the overall optimum solution may or may not include these options depending on the balance of benefits and disadvantages. One important option for further reducing the probability of inadvertent intrusion is to locate the facility away from known natural resources, thus reducing the probability of inadvertent intrusion that might happen during prospecting for other natural resources; this is considered in the site selection stage. There are several additional options that could be considered, for example, options relating to repository design. Features such as reinforced structures or minimizing the footprint of a repository by building a tall and thin repository could make intrusion more difficult and hence reduce the probability of inadvertent intrusion. The latter is less likely to be an option for conventionally mined repositories in many locations due to limitations posed by other factors (e.g. the mechanical stability of excavations); however, disposal in deep boreholes (an option for some wastes) could result in a smaller footprint.

The most interesting additional option is the use of markers to identify the location of the facility and warn future generations of the presence and contents of the facility. Markers could take the form of land use records, a fence or surface warning sign, a physical marker or man-made barrier just above the facility or a marker or sign in the access tunnel. However, it may just be better to keep it a secret!

The US Waste Isolation Pilot Plant (WIPP) undertook a project on markers (Sandia, 1992; John Hart and Associates, 2004) and identified that there are a number of key issues to be addressed such as: 'Will the mark be understood?' 'Will it be ignored?' 'Will it arouse curiosity?' 'Will it last?' and 'What is the message?' In fact, the message is rather complicated as it has to convey the following points: (1) there is a message here; (2) it is important so do not ignore it; (3) this is not a place of reverence; (4) danger present; (5) the danger still exists in your time (our future); and (6) the danger only exists if you disturb the site. It is safe if you shun the site.

The WIPP marker project (Sandia, 1992; John Hart and Associates, 2004) identified a number of

possible warning signs and surface markers ranging from plaques or stone markers containing simple text messages such as 'poisonous radioactive waste buried here do not dig or drill here', to symbols depicting radioactivity at depth, to elaborate sculptures intended to impart a sense of unease in the onlooker (such as the 'field of thorns' or 'menacing earthworks').

## Discussion

The effectiveness of surface markers for protection against inadvertent intrusion into a geological disposal facility in the far future is not easy to determine. There are many historical examples of markers and warning signs being ignored by intrepid explorers, archaeologists and tomb robbers; the 'Indiana Jones' syndrome. In fact, they may arouse curiosity and attract attention and, consequently, inadvertent intrusion. Conversely, there are well known examples of sites that have remained undiscovered for many years because the records or surface markers have been lost: the Inca city of Machu Picchu in Peru was undiscovered for 400 years, the tomb of the Chinese Emperor Qin in Xi'an was undiscovered for 2000 years and the tombs of the 'three royal dentists' near the step pyramid at Saqqara in Egypt were undiscovered for 4500 years. Thus, history indicates that surface warnings and markers are ineffective even in the short and medium term and suggests that the absence of surface markers may actually be effective in delaying inadvertent intrusion in the medium term (up to a few thousand years). However, it is important to recognize that a geological disposal facility is located deep underground, a significant distance below any surface marker, and it would remain inaccessible unless the investigator resorted to deep drilling or major excavation, both very expensive operations. The presence of a simple surface marker such as a small monument or plaque may serve to remind the investigators to consult the old records and will not in itself prompt expensive operations such as deep drilling at that location. Thus history is not necessarily the key to future behaviour. The important questions are 'How can we warn future generations?' and 'How can we ensure that they don't think that they have found treasure?' These questions are raised in the film *Into Eternity* describing the Finnish ONKALO deep geological disposal research facility, which even suggests that we need to 'remember to forget'.

It is important to remember that this is a multidimensional problem. It is imperative that optimization of protection for the facility is considered for all exposure pathways and scenarios, not just for the inadvertent intrusion pathway. Hence there is a need to balance expected events, such as the groundwater and gas migration pathways, against events that may not occur, such as inadvertent intrusion and severe natural disruptive events. It is important that the performance of the repository for the migration pathways is not prejudiced by optimizing the design to reduce the probability of intrusion.

The multidimensional aspect of the optimization also requires input from a range of stakeholders. It is important to come to an agreed decision on the overall approach: in other words 'How important is protecting the intruder?' Another important consideration will be 'How do we prolong knowledge of the repository?' as this will extend the period of indirect oversight and hence delay the possibility of inadvertent intrusion. Finally, answers to questions such as 'Are obvious warning signs or obstructions desired or is it best to rely on records?' are best determined in consultation with local stakeholders.

The output of such discussions will influence the final facility design, particularly the layout and location of surface features, and therefore it is important that this is addressed in a timely way. Each site will have its own optimum solution.

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