INTERNATIONAL UNDERSTANDING OF REVERSIBILITY OF DECISIONS AND RETRIEVABILITY OF WASTE IN GEOLOGICAL DISPOSAL

Countries around the world are researching, developing and demonstrating disposal of long-lived radioactive waste in engineered repositories located in suitable deep underground geological formations as the reference solution to protect present and future generations and the environment. In some countries, actual implementation of geological disposal projects is only a few years away. Countries are also considering whether and how to incorporate the concepts of reversibility and retrievability into their repository programmes. Reversibility implies a disposal programme that is implemented in stages and that keeps options open at each stage, and provides the capacity to manage the repository with flexibility over time. Retrievability is the possibility to reverse the step of waste emplacement. It is generally recognized that it is important for each country to clarify the meaning and role of reversibility and retrievability for its programme and that long-term safety is paramount. The present leaflet summarizes the current understanding developed in the NEA international project on reversibility and retrievability (http://www.nea.fr/rwm/rr). The leaflet includes a generic Retrievability Scale that is adaptable to most countries' programmes and could help support dialogue with stakeholders.

Repository objective and life phases

The objective of a geological repository is to provide protection of humans and the environment from the hazard that the radioactive waste would pose over time. Once the waste is emplaced, there is no intention to retrieve it. Ultimately, safety is to be ensured by the man-made barriers and the host geology fulfilling complementary functions, and it will be necessary to close the repository according to an agreed plan. For this reason, no material other than packaged ultimate waste should be disposed of in the repository. In this context, waste storage is not an alternative to disposal; rather it is a step in the management strategy leading to final disposal.

A geological repository involves three main phases (Fig 1) whose durations vary amongst national programmes depending on design and each country's approach to decision making:

- The **pre-operational phase**: during this phase, the repository is designed, the site is selected and characterized, the man-made materials are tested and the engineering demonstrated, the licenses for building and operation are applied for and received, and construction begins. A baseline of environmental conditions is also obtained.
- The **operational phase** may be divided into three periods:
  - (a) The *emplacement period*: the waste packages are emplaced. The environmental conditions are continuously monitored and compared to the baseline data; R&D continues; the regulator performs regular inspections for operational safety and reviews of the long-term safety case. New underground galleries may be built and partial backfilling and/or sealing of galleries and repository areas may also take place.
  - (b) The *observation period*: after all waste packages are emplaced, it might be decided to monitor parts of the repository and to keep some accessibility to part of the waste while additional performance confirmation takes place.
  - (c) The *closure period*: backfilling and sealing are performed according to design and access from surface to the underground facility is terminated. Surface facilities may be dismantled.
- The **post-operational phase** may be divided into two periods:
  - (a) A *period of indirect oversight*: after closure, safety is assured through the intrinsic, passive provisions of the repository design. Nevertheless, it is plausible to expect continued monitoring of the baseline environmental conditions, and some remote monitoring. The relevant international safeguards controls would continue to apply. Archives on technical data and configuration of waste packages and the repository would be kept, as well as markers to remind future generations of its existence.
  - (b) A *period of no oversight*: eventually, after hundreds or thousands of years, loss of oversight and memory can be expected to take place, either progressively or following major unpredictable events such as war or loss of records.

Figure 1

Reversibility, retrievability: what are they?

Reversibility refers to decision-making during project implementation: it involves ensuring that the implementation process and technologies maintain flexibility so that, at any stage of the programme, reversal or modification of one or a series of previous decisions may be possible if needed, without excessive effort. A decision of partial backfilling, for example, may be made with reversibility in mind. Each major authorization in repository implementation (Fig. 1) can be seen as an assessment of whether the process can continue as foreseen or whether one of the reversibility options should be exercised (Fig. 2). Reversibility implies a willingness to question previous decisions and a culture that encourages such a questioning attitude. It also implies some degree of retrievability of waste.

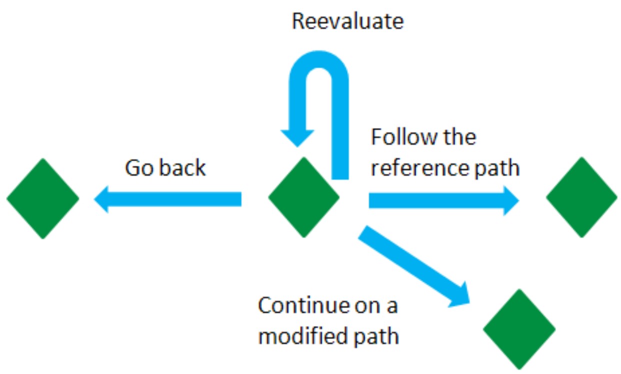

Figure 2: Potential outcomes of options assessment, including reversal

Retrievability is the ability to retrieve emplaced waste or entire waste packages. Retrievability is an intrinsic part of the concept of storage. Retrievability is not part of the basic, long-term safety concept of a waste repository. Waste should never be emplaced in a repository if the long-term safety case is not robust without reliance on retrievability. However, retrievability may still contribute to confidence in safety and retrieval may become desirable for non-safety reasons. Retrievability provisions may also provide additional flexibility during operation.

Even if the package is degraded, retrieval of the waste may still be carried out using appropriate techniques. If the waste materials have migrated away from their initial emplacement location, retrieval of the waste could require mining techniques similar to those used in ore extraction.

Retrieval of waste may be desirable for reasons other than safety, e.g., if the waste were to be re-categorized as a resource. The safety case for a repository, however, will always rest on passive safety considerations and not be dependent on the possibility of retrieval.

During the operational phase, reversibility and retrievability translate into practice a precautionary approach to waste disposal. During the post-operational phase, retrievability is facilitated by the confinement and containment design of any geological repository. In the distant future, waste will still be retrievable, although with greater effort and expense as time passes. The ability to retrieve is thus a matter of degree rather than of the presence or absence of the possibility to retrieve the waste. Research and development may provide ways to reduce the degree of difficulty of retrieval (Fig. 3).

Fig. 3a: Bentonite rings removal test in view of waste package retrieval in Sweden (Äspö HRL, 2006)

Fig. 3b: Retrieval of a disposal HLW package from a simulated emplacement cell in France (ESDRED programme, 2008)

A retrievability scale for stakeholder dialogue

One of the key issues for stakeholders considering the implementation of a geological disposal facility for radioactive waste is the ease of waste retrieval from a repository. The ease will vary according to the accessibility of the waste during the life phases of the repository. A generic retrievability scale has been developed to illustrate qualitatively the degree and type of effort that is needed to retrieve the waste according to the stages in its lifecycle before and after its emplacement in a repository (see Table 1 and Fig 4). The scale also shows the relationship between the effort needed for retrieving the waste and the corresponding balance between active controls and passive safety of the repository. The more difficult the retrieval is, the higher its cost will be.

Waste lifecycle stages and retrievability: a textual description

For illustration purposes, the lifecycle of packaged [1]waste can be reduced to 6 stages, as identified in Table 1. For each stage, the table also identifies the main elements of passive safety and active control, as well as the degree and type of retrieval effort. **Stage 1** represents packaged waste placed in interim storage. **Stage 2** is waste moved from interim storage to a repository facility a few hundred meters deep, which may require further re-packaging. Additional protective barriers around the waste emplacement cell are put in place in **Stage 3**: backfill (against rock movement, generally) and/or sealing (against water and gas circulation). The access galleries to the cell still need active maintenance, e.g. ventilation. These galleries are backfilled and/or sealed in **Stage 4**, which may coincide with the closure of the whole disposal zone in which the gallery is located or indeed of the whole underground facility. At this stage, maintenance of the disposal zone (or the whole underground facility) is no longer necessary, but the facility may still be monitored remotely. In **Stage 5** the repository is closed: access from surface has been sealed, and surface facilities have been dismantled. **Stage 6** is the final disposal state. Although the integrity of the waste packages cannot be guaranteed, the waste is still confined within the facility. By this time, the level of radioactivity has been reduced significantly. Safety will not depend on maintenance or monitoring. Measures intended to ensure preserving knowledge and memory of the site may continue.

[1] The type of package may be a steel drum, a concrete container, a steel primary package inside a concrete or steel container, etc.

TABLE 1: Waste lifecycle stages, ease of retrieval, and specific elements of passive safety and active control.

Stage and Location of the Waste		Ease of Retrieval	Specific Elements of Passive Safety	Specific Elements of Active Control
1	**Waste Package(s) in storage**	Waste package retrievable by design	Waste form and its storage container	Active management of storage facility including security controlled area
2	**Waste Package(s) in disposal cell***	Waste package retrievable by reversing the emplacement operation	Waste form and disposal container Hundreds of meters of rock Engineered disposal cell	Active management (including monitoring) of disposal cells and disposal facility. Security controlled area
3	**Waste Package(s) in sealed disposal cell**	Waste package retrievable after underground preparations	As in previous stage, plus backfill/sealing of disposal cell	Monitoring of disposal cells possible. Active management of access ways to disposal cell seals. Security controlled area
4	**Waste Package(s) in sealed disposal zone**	Waste package retrievable after re-excavation of galleries	As in previous stage, plus backfill/sealing of underground galleries allowing access to cells	Monitoring of disposal cells potentially possible. Security controlled area. Detailed records and institutional controls for a specified period, including international safeguards.
5	**Waste Package(s) in closed repository**	Waste package retrievable after excavating new accesses from surface. Ad-hoc facilities to be built to support retrieval.	As in previous stage, plus sealing of shafts and access drifts to ensure long term confinement of the waste within the underground facility.	Maintaining records Regular oversight activities as long as possible (e.g. environmental monitoring, possibly remote monitoring, security controls and international safeguards).
6	**Distant future evolution**	Waste package degrading with time. Waste ultimately only retrievable by mining	Geology and man-made barriers Reduction in level of radioactivity.	Specific provisions for longer-term memory preservation, e.g. site markers.

* Depending on the national programme and on the type of waste, the waste package emplacement room may be a vault, a cell, a section, etc. The term “cell” used here is generic to all these cases.

Waste lifecycle stages and retrievability: a graphical description

The connection between retrievability and passive safety along the lifecycle of radioactive waste is represented graphically in Fig. 4. The figure is generic and can be applied to a variety of national programmes.

The duration of the waste stages and the duration of the repository life phases will depend on decisions that will be made in each national programme during the implementation of the geological facility. At each decision point during implementation, which could last up to 100 years, various factors will be taken into account, including ease of retrieval of waste packages; the need for active control; changes affecting long term safety; and costs in terms of economics, dose exposures, hazards, etc.

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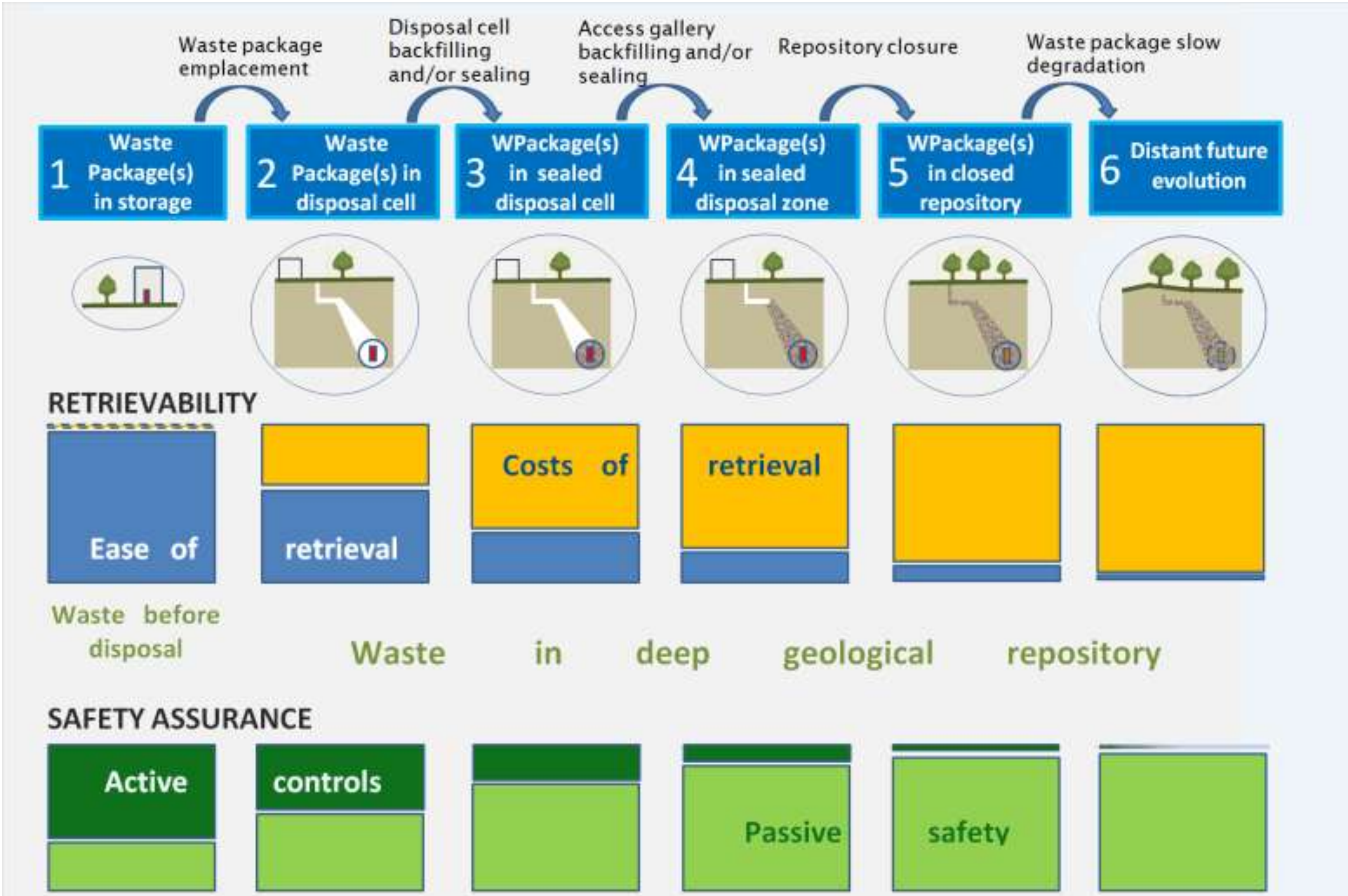

Fig.4: Lifecycle stages of the waste, illustrating changing degree of retrievability, passive vs active controls and costs of retrieval in a deep geological repository (actual size of boxes may vary depending on the repository design)

REVERSIBILITY AND RETRIEVABILITY APPLIED DURING THE OPERATIONAL PHASE OF A GEOLOGICAL REPOSITORY OF LONG-LIVED RADIOACTIVE WASTE TRANSLATE INTO PRACTICE A FLEXIBLE, PRECAUTIONARY APPROACH TO WASTE DISPOSAL. RETRIEVABILITY IS A MATTER OF DEGREE RATHER THAN OF THE PRESENCE OR ABSENCE OF THE POSSIBILITY TO RETRIEVE THE WASTE. EVEN THOUGH RETRIEVABILITY IS NOT PART OF THE LONG TERM SAFETY CONCEPT FOR DISPOSAL, THE WASTE CONTINUES TO BE RETRIEVABLE, ALBEIT POSSIBLY AT GREAT EFFORT AND EXPENSE. RESEARCH AND DEVELOPMENT MAY PROVIDE WAYS TO REDUCE THE DEGREE OF DIFFICULTY OF FUTURE WASTE RETRIEVAL.