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Reversibility and Retrievability (R&R) for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel

Intermediate Findings and Discussion Document of the NEA R&R Project

September 2010

Because they touch on freedom of choice and its relationship to safety, the concepts of Reversibility and Retrievability (R&R) link societal and technical considerations, and tend to be central in the debate on "disposal" when, besides the technical audiences, the public and society at large are involved; hence the continued interest in these topics. This draft report deals with the concepts of reversibility and retrievability for the deep disposal of high-level radioactive waste and spent fuel. It documents the results of an initiative that was started by the NEA in 2007-2008 with the goal of providing a neutral overview of relevant issues and viewpoints in OECD countries. Some of the discussion will also be applicable to related situations such as that of planning a repository for low- and intermediate-level wastes. The point of view and intended audience for this report is that of someone planning or designing a final repository for high-level wastes or spent nuclear fuel, not that of someone contemplating retrieval. At this stage in the project, the arguments and conclusions that are presented are based on the work of the R&R Working Group. Inasmuch as the discussions of that group have been largely limited to members of the waste management community, these conclusions may not reflect adequately the views of other constituencies. It is hoped that the discussions at the Reims conference in December 2010 will help remedy this.

claudio.pescatore@oecd.org

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FOREWORD

At one time disposal was often treated as if it were a relatively short-lived activity to be completed in the time span of perhaps a single generation – the goal being to provide a facility that could safely contain radioactive waste without any further action or intervention by future generations. Increasingly, the implementation of a disposal project has come to be viewed as an incremental process in a series of successive steps, likely taking several decades to complete. Apart from the concept of protection of future generations, this changing vision includes an assumption of the involvement of succeeding generations in the process and a need to preserve as much as practicable their ability to exercise choice. As a result of this evolution, monitoring is an activity under study to inform this process prior to closure of the facility, and monitoring, surveillance, and information and memory keeping are also being studied for consideration after closure of the facility.

At the same time, the chosen policy of concentrating and confining the waste in a repository, as opposed to a policy of dilution and dispersion, creates de facto a situation of potential availability of the waste for future retrieval. To what extent retrieval can or should be further facilitated in designing a repository, and if so over what time scales, are issues of continued interest in NEA member countries. The intention of the present report is to help national reflections by providing a neutral overview of relevant issues and viewpoints in OECD countries based on the current understanding and views of specialists from the waste management community as well as from stakeholders, opinion leaders and from researchers in the technical and social sciences.

The point of view and intended audience for this report is that of someone planning or designing a repository for high-level wastes or spent nuclear fuel, not that of someone contemplating retrieval. Some of the discussion will also be applicable to related situations such as that of planning a repository for low- and intermediate-level wastes.

The report, when finally completed, will document the results of a 4 year project and study launched in 2007 by the OECD/NEA Radioactive Waste Management Committee (RWMC), which is a forum of senior national representatives of operator, regulator, policy-making, and R&D organisations in the field of radioactive waste management. The Committee promotes safety in the short- and long-term management of radioactive waste and assists the NEA countries and the wider OECD family by providing guidance on the solution of radioactive waste problems, including consideration of stakeholder confidence. Major milestones in the project have been the conduct of a bibliographic survey, a survey of NEA countries' positions, and discussions within an ever increasing group of interested parties that culminated with an international conference in Reims 15-17 December 2010. The project is documented on the web at www.nea.fr/rwm/rr/. Inasmuch as the membership of the R&R group has been largely limited to members of the waste management community, the dominant views present herein may not reflect adequately the views of other constituencies. The discussions at the Reims conference in December 2010 will help remedy this.

Acknowledgements

This report is based on the work of the RWMC Working Group on Reversibility and Retrievability. We would like to thank the many participants from 16 countries and 3 international organizations who contributed to the Working Group, either by direct participation, by responding to project questionnaires, or by commenting on previous drafts of the report. Financial contributions towards the work on the project have been provided by Belgium, Canada, France, Germany, Japan, Spain and Switzerland. The project manager was Claudio Pescatore of the NEA, assisted by a consultant, Richard Ferch. Gloria Kwong also assisted in early drafts of the report.

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1. INTRODUCTION

1.1 Background

Reversibility and retrievability (R&R) are not new concepts, either in science and technology or in radioactive waste management.

- In 1969, the United States National Academy of Sciences, in its report to Congress titled *Technology: Processes of Assessment and Choice*, observed that: "Other things being equal, those technological projects or developments should be favored that leave maximum room for maneuver in the future. The reversibility of an action should thus be counted as a major benefit; its irreversibility, a major cost." [Ref. 1]

- One of the *Proposed Goals for Radioactive Waste Management*, in the NUREG-0300 document dated 1978 [Ref. 2] and prepared by a task group for presentation to the United States Nuclear Regulatory Commission, reads as follows: "If wastes are disposed on earth, their retrievability - assuming a technology as advanced as present - should not be precluded."

- The WIPP disposal facility for low- and intermediate long-lived radioactive waste is licensed based on its waste being, in principle, retrievable over a period of a few centuries after closure of the repository [Ref. 3].

- Low-level short-lived radioactive waste disposal facilities in some countries are operating based on the retrievability concept. In some cases (Spain) specific design adaptations were required by the regulator.

Interest in reversibility and retrievability of high-level radioactive waste and spent fuel has been steadily increasing since the late 1970s, as can be observed from a bibliography prepared for the present study [Ref. 4] and the remainder of this document. There still exist open issues, e.g., to what extent retrievability should be sought actively as opposed to a policy of not unnecessarily precluding it. In 2008 the NEA RWMC, in its Collective Statement on "Moving Forward with Geological Disposal of Radioactive Waste" [Ref. 5], concluded that: "There is general recognition that it is important to clarify the meaning and role of reversibility and retrievability for each country, and that provision of reversibility and retrievability must not jeopardise long-term safety."

This report deals with the concepts of reversibility and retrievability for the deep disposal of high-level radioactive waste and spent fuel. It documents the results of an initiative which was started by the NEA in 2007-2008 (see Box), with the goal of providing a neutral overview of relevant issues and viewpoints in OECD countries, drawing on the current understanding and views of specialists from the waste management community as well as from stakeholders, opinion leaders and from researchers in the technical and social sciences. The remainder of this document does not attempt to cover all of these discussions, but focuses on some of the most important issues. Inasmuch as the membership of the R&R group has been largely limited to members of the waste management community, the dominant views present herein may not reflect adequately the views of other constituencies. The discussions at the Reims conference in December 2010 will help remedy this.

Although some issues that would be faced by someone actually planning to retrieve or recover wastes are mentioned, the point of view and intended audience for this report is that of someone planning or designing a repository for high-level wastes or spent nuclear fuel, not that of someone contemplating retrieval. Some of the discussion will also be applicable to related situations such as that of planning a repository for low- and intermediate-level wastes.

Box: The NEA R&R Project

The NEA R&R initiative leading to this report is documented at www.nea.fr/rwm/rr/. The modus operandi of the project has been one of continuous refinement of its findings through the involvement of an increasingly wide spectrum of interested parties and viewpoints.

The project was carried out in several phases.

- The first phase, in 2007-2008, was the compilation of a bibliography of references on the topic. The bibliography was updated through 2010.
- The second was a data gathering phase through use of a questionnaire to elicit information on the current status of disposal programmes in member countries with respect to the role(s) of reversibility and retrievability in those programmes. The questionnaire was issued to NEA member countries in May 2008. A working group was convened and a series of meetings were held at which the responses were analyzed, following which topical discussions were held on a variety of subjects arising from the analysis.
- The third phase was the preparation and holding of an international conference and dialogue, 14-17 December 2010 in Reims, France. This draft report and the Project's draft leaflet on R&R serve as discussion documents for the conference.
- The fourth phase will consist of the finalisation of the Project and its documentation within Summer 2011.

1.2 Structure of the Report

This report is structured as follows:

Chapter 1 provides background information to the present report, which deals with the concepts of reversibility and retrievability (R&R) for the deep disposal of high-level radioactive waste and spent fuel. It documents the R&R project that was started by the NEA in 2007-2008 with the goal of providing a neutral overview of relevant issues and viewpoints in OECD countries.

Chapter 2 provides an overview of the historical evolution of the retrievability and reversibility concepts since the late 1970s and reviews and defines terminology for this report. It observes that R&R are linked to the reaffirmation in several circles of the guiding principle of preservation of options for future generations and that one important reason why there is difficulty in discussing reversibility and retrievability is that important basic terms and concepts are understood differently by different stakeholders or used differently in the different countries.

Chapter 3 outlines some of the major considerations in relation to reversibility, retrievability and recoverability during the various repository phases. It identifies the determining factors that impact the potential for waste retrieval and/or step reversal. Technological challenges and non-technical aspects as well as associated costs and safeguards issues are discussed in this chapter. Benefits and shortcomings are summarised.

Chapter 4 reviews R&R in the context of decision-making for repository development. Decisions will follow one another sequentially and will be reviewed, and at times determined, by the presence of the regulator. Hence an important attention is given to regulatory issues. Communication aspects are also covered and a generic, international Retrievability scale is presented.

Chapter 5 summarizes the similarities and differences of reversibility, retrievability and recoverability in various NEA countries and the views of the R&R working group members to that effect. Countries deal differently with the subjects of R&R. While there is considerable agreement on many of the principles underlying reversibility, retrievability and recoverability, there is less degree of unanimity on whether and if so, how these principles might be put into practice in disposal programmes

Chapter 6 presents major observations and conclusions of this report.

2. HISTORICAL PERSPECTIVE AND TERMINOLOGY

As observed in Section 1.1, reversibility and retrievability (R&R) are not new concepts either in science and technology or in radioactive waste management. R&R are motivated in part by the desire to abide by a guiding principle of not denying future generations a certain degree of freedom of choice. This guiding principle has arisen both in technical documents and through societal feedback, and needs to be considered along with other principles identified in international guidance governing radioactive waste disposal.

Terminology matters a great deal when discussing repository concepts and R&R. In this chapter we define terminology for the purpose of this report, in order to avoid potential diverging or confusing uses of major terms and concepts. Ultimately, it is important that basic terms and concepts are understood within and across countries and it is paramount that differences in national terminology are recognized and taken into account when performing comparison studies.

2.1 Overview of developments during the past three decades

Since the late 1970s, there have been discussions and positions taken on R&R in almost every national repository programme.

From the 1980s the example may be given of the KBS-3 disposal study report [Ref. 6], which observed: "It must be assumed that future generations will bear the responsibility for their own conscious actions. What is of importance in this context is to provide them with the best possible information as a basis for their decisions, i.e. to make sure that information on the location, design and function of the final repository is carefully recorded and preserved. If, at some time in the future, people wish to retrieve and recover the copper or the spent fuel present in the final repository, they will then be aware of and able to cope with the radiological risks." Dating from the 1980s is also the generic regulatory position of the US Environmental Protection Agency (EPA) applicable to any spent nuclear fuel or high-level or transuranic waste disposal facility in the USA, which states that "Disposal systems shall be selected so that removal of most of the wastes is not precluded for a reasonable period of time after disposal" [Ref. 7].

- It is of interest to observe that, in the KBS study of 1983, retrieval of the waste is predicated not on safety, but on allowing future generations a freedom of choice on retrieving useful materials. Retrievability is presented not as requiring special technical provisions, but as a feature that is inherently present at all stages of a repository's lifecycle, and that it needs to be supported through information preservation provisions.

- The EPA regulations explain that retrievability is mandated in order to provide *added confidence* in meeting the containment requirements of the regulations. That is, if waste stays retrievable over a certain period of time, this also means that it will not have dispersed in nature. In this sense, retrievability offers an additional assurance of safety, although it is not a requirement for safety. The inclusion of retrievability in regulation is described, additionally, as also allowing further freedom of choice to future generations, including for safety reasons: "The intent of this provision (191.14(f)) was not to make recovery of waste easy or cheap, but merely possible in case some future discovery or insight made it clear that the waste needed to be relocated." Because retrievability plays a confidence-boosting, just-in-case role, EPA indicates that retrieval needs to be feasible, but that it need not be prepared for: "To meet this assurance requirement, it only needs to be technologically feasible (assuming current technology levels) to be able to mine the sealed repository and recover the waste—albeit at substantial cost and occupational risk." Later, the WIPP repository was certified for operation in 1998 based on the above requirements[1].

In the 1990s the debate over retrievability moved from the question of *not unnecessarily impeding* retrieval towards the question of *facilitating* potential retrieval, e.g., through specific design provisions and adaptive decision-making, on grounds not only of further favouring the freedom of choice of future generations and in response to concerns in case safety issues might arise in the course of time, but also in order not to cause social strife.

- In 1991, the French Radioactive Waste Act requested a feasibility study of a deep geologic repository, with or without the provision of reversibility. During the siting phase of the Underground Research Laboratory (URL) (1992-1998) reversibility appeared to be a significant issue for public acceptance and decision makers, and the government requested that "a logic of reversibility" be followed in developing disposal systems [Ref. 8].
- Another example is the conclusions of the Seaborn environmental assessment panel's 1998 report on the original Canadian repository concept [Ref. 9]. The panel stated that there was not yet sufficient societal acceptance of the concept to proceed. Among the reasons given for this lack of acceptance was a desire on the part of many stakeholders for the concept to better accommodate monitoring, retrieval, recycling and the emergence of new technology.
- A NEA survey published in 1999 [Ref. 10] observed that : "The implementers and regulators are more willing than ever to heed the wishes of the public in so far as these do not compromise the safety of disposal facilities. One common wish is for strategies and procedures that allow long-term monitoring, with the possibility of reversibility and retrievability. A number of programmes now consider these issues explicitly."
- In June 2000, the German Government declared a moratorium on further developing the Gorleben site for HLW and spent fuel disposal [Ref. 11]. One of the reasons given was the need to wait for further developments in the field of retrievability. This may be an example of the use of "retrievability" for political expediency.

At the same time, in the 1990s, a strong technical focus on retrievability was also being maintained. Technical workshops were held, e.g., one hosted by Nagra in 1997 and one by Andra in 1998. Experiments on retrieval were designed and later started by SKB [Ref. 12]. The Swedish regulator commented positively on those developments as follows: "Even if there can be no question of planning for retrieval when it ultimately comes to the final disposal stage, i.e. of viewing the repository as an interim storage facility, SKI is of the opinion that SKB must develop methods for retrieval. In SKI's opinion, methods for retrieval should be developed and full-scale demonstration conducted no later than when a decision is made to start a detailed investigation. Therefore, it is positive that SKB has started to study retrieval technology and SKI is looking forward, with interest, to the results of the planned retrieval experiment at the Äspö Hard Rock Laboratory" [Ref. 13]. SKB completed its canister retrieval test in 2006 [Ref. 14]. Also, in 1996-1997 Nirex ran successful retrieval experiments [Ref. 15].

The first major international publication dedicated to retrievability is the proceedings of a seminar held in Sweden in 1999 [Ref. 16]. The papers presented covered a wide range of topics related to the subject, and these proceedings may still be considered the most comprehensive and detailed international reference on

[1] In 1996, the EPA released its regulations specific to the WIPP site (40 CFR 194). According to this regulation removal had to be shown to be feasible using existing technology, and the licensing application had to include plans for removal in case the EPA were to revoke certification.

retrievability. At approximately the same time, the European Commission (EC) sponsored a study called the *Concerted Action on the Retrievability of Long Lived Radioactive Waste in Deep Underground Repositories* [Ref. 17]; several of the contributors to this study presented papers at the *Swedish* conference. In parallel, the NEA published its summary report *Reversibility and Retrievability in Geologic Disposal of Radioactive Waste – Reflections at the International Level* [Ref. 18]. The box below reports factors that have been invoked in favour of and against retrievability.

Box: Possible factors favouring and opposing retrievability provisions [NEA-3140 – Ref. 18]

Factors potentially favouring retrievability:

- technical safety concerns that are only recognised after waste emplacement and/or changes in acceptable safety standards;
- a desire to recover resources from the repository, e.g. components of the waste itself, or the recognition or development of some new resource or amenity value at the site;
- a desire to use alternative waste treatment or disposal techniques that may be developed in the future;
- a desire to respond to changes in social acceptance and perception of risk, or changed policy requirements.

Factors potentially opposing retrievability:

- uncertainty about negative effects, including conventional safety and radiological exposure of workers engaged in extended operations and/or associated monitoring, or marginal gains;
- the possibility of failure to seal a repository properly, due to the adoption of extended or more complex operational plans to favour retrievability;
- the favouring of irresponsible attempts to retrieve or interfere with the waste during times of political and/or social turmoil when safeguards and monitoring features are no longer in place;
- a possible need for enhanced nuclear safeguards.

The NEA also introduced the concept of reversibility internationally, for the first time, as a distinct concept to that of retrievability. Inspiration was taken from the Swiss EKRA-I study [Ref. 19], which is part of the basis of the current Atomic Law in that country, and from a contribution by T. Papp (SKB) in 1998 [Ref. 20], where he introduced the concept of "backtracking", i.e. "The ability to retract any step in the stepwise sequence of conditioning, deposition, backfilling and closure". In practice, in a reversible approach the opportunity of retrieving the waste may be examined at each major decision. A sequence of shared decisions on not having to exercise the retrieval option on safety reasons could ease any decisions on moving forward and eventually closing the facility.

In the current decade, in addition to the various developments in individual national programmes (see later in this report), there have been two publications from international agencies that bear importantly on the topic. The first of these is a report entitled *Stepwise Approach to Decision Making for Long-term Radioactive Waste Management - Experience, Issues and Guiding Principles* [Ref. 21], which deals with topics related to adaptive, staged or stepwise decision-making, including reversibility. The second is *Disposal of Radioactive Waste: Technological Implications for Retrievability* [Ref. 22], which focuses on technical issues related to retrievability.

On the technical side, the technology-based EC-sponsored ESDRED project performed a desk study based respectively on the French (Andra) repository concept (horizontal disposal holes excavated in a clay host formation) and the German (DBE-TEC) repository concept (vertical boreholes drilled in a salt host formation). The study of the Andra concept was in the form of a peer review. In both cases [Ref. 23] no counter indications arose with respect to the proposed design concepts.

The Implementing Geological Disposal – Technology Platform (IGD-TP) was launched in November 2009 with support from the EC via the Secretariat SecIGD project [Ref. 24]. The SecIGD is driving the development of the Strategic Research Agenda (SRA) for subsequent implementation as part of the Deployment Plan. Retrievability is considered to be one of the key topics of the SRA.

Also in the current decade, two important events have taken place involving retrievability: (a) the actual retrieval of a waste package at WIPP on two occasions, because of concerns of quality assurance. The first retrieval was requested by an environmental regulator, and the second was undertaken on the initiative of the implementer [Ref. 25]; and (b) the active consideration being given to the retrieval or recovery of waste currently emplaced in the Asse mine [Ref. 26]. Although the Asse situation is not considered to be representative of the course of events to be expected in a repository for high level waste, the history and difficulties encountered are nevertheless informative in this context.

Most recently, the Blue Ribbon Commission on America's Nuclear Future is holding hearings on waste disposal approaches and options, and retrievability is one element being raised. [Ref. 27]

Current interest in the topic of R&R is documented in the present text, which reports the findings of the latest NEA initiative in this area. Its specific goals have been (i) to bridge regulatory, policy and implementation positions; (ii) to bring together specialists and laymen in order to review the efforts and national positions so far; (iii) to engender a more comprehensive understanding of the issues at play; and (iv) to document these findings.

2.2 Underlying principles

From an international perspective the 1995 IAEA Safety Fundamentals on Principles of Radioactive Waste Management [Ref. 28] identified the following *two principles* for guiding waste disposal:

- **Protection of future generations**: radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact which are acceptable today.
- **Burdens on future generations**: radioactive waste shall be managed in such a way that will not impose undue burdens on future generations.

This 1995 document has since been superseded by a newer Safety Fundamentals document [Ref. 29] which subsumes both of the above principles in a single fundamental principle:

- **Protection of present and future generations**: people and the environment, present and future, must be protected against radiation risks.

The supporting text describing this fundamental principle of protection makes it clear that both of the previous principles are considered to be aspects of this fundamental principle:

The waste disposal literature contains, in addition, frequent references to a third guiding principle, namely that of preserving options for future generations. An early formulation, which is still valid today [Ref. 30] is as follows:

- **Preservation of options for future generations** As knowledge is increasing with time, and where value judgements are changing, future generations shall be given the freedom to make their own decisions with regard to the utilization of resources for safety and long-term protection. Furthermore, a repository should not be designed so that it unnecessarily impairs future attempts to retrieve the waste, monitor or repair the repository

Examples of recognition of this guiding principle include references to early studies and regulations, such as [Ref. 2, Ref. 6, Ref. 7]. The current positions reported by the Belgian and Canadian programmes are in line with this guiding principle as well [Ref. 31]. A weaker form of this principle is the NAS formulation of the precautionary principle:

- **Precautionary principle in selecting technical options** "Other things being equal, those technological projects or developments should be favored that leave maximum room for maneuver in the future. The reversibility of an action should thus be counted as a major benefit; its irreversibility, a major cost." [Ref. 1]

The EKRA-2000 study [Ref. 19] on which the current Swiss "monitored long-term geological disposal" concept relies can be related to the application of the latter guiding principle. After examining various options based on a hierarchy of values as reported in the text box below, the study concludes: "In the event that in-depth investigations as part of concrete projects show that the concept of monitored long-term geological disposal can provide a level of safety which is comparable with that of geological disposal, then the former should be the preferred option given the easier reversibility which it offers."

Both the EKRA and KASAM studies involved ethicists in the formulation of the reference guiding principles. Associated with all the above principles is, in Andra's view, an attitude of modesty and humility, which promotes a prudent approach when considering the current level of scientific knowledge. [Ref. 32, section 2; Ref. 33]

Box: EKRA-2000's values and objectives and their evaluations for radioactive waste disposal concepts in Switzerland [Ref. 19]

EKRA defines the values and objectives of radioactive waste disposal and organises and evaluates them hierarchically. Highest priority is assigned to safety:

– safety of man and the environment
– freedom for every generation, fairness between social and population groups and between generations
– observing the producer pays principle
– acceptance

Much of the controversy surrounding retrievability is associated with the choice between the guiding principle of reducing undue burdens on future generations and the guiding principle of preserving their options. While preservation of future options allows future generations to make their own decisions in the light of new information and changing needs, the mere fact of preserving the option of choice inevitably imposes burdens, including at a minimum the burden of having to make decisions. There may also be more tangible burdens. In preserving options for future generations, if it were decided to keep a repository open to facilitate retrieval of its contents, these tangible burdens could include: (i) operational exposures, (ii) continuing risks of accidental releases; (iii) financial provisions to cover operating costs; and (iv) the need to support continuing reliance on institutional control. The NAS guiding principle of avoiding or limiting irreversible choices represents one way of reconciling or balancing these two other principles.

A recent NEA study [Ref. 34] has investigated what countries may consider as "undue burden". The term "undue burden" was interpreted by some country respondents to mean financial burden, and by others to mean the burden of potential radiological exposure. During later discussions, the burden on immediately succeeding generations of the duty to complete disposal projects initiated in the present was also mentioned. The study concluded that continuing discussion of terms such as "undue burden" and their interpretation would be helpful.

Two important questions arise from the guiding principle of preserving options: 1. "how should options be preserved?"; and 2. "for how long a time is it considered reasonable or desirable to preserve these options?". The answers to these questions depend upon technical, political and social factors, and are therefore variable from country to country. In addition to depending on such technological factors as the nature of the waste (spent fuel containing known energy resources vs. HLW) and the geological surroundings (which affect both the likelihood and consequences of radioactive materials reaching the environment as well as the ease of retrieval), there are also societal factors that have a major influence, e.g. societal attitudes towards freedom of choice vs. assurance of safety, and the degree of optimism with respect to future technological developments, which varies with time and place. *It is reasonable to expect that the points of balance among these conflicting factors will differ from one country to another and even from one time to another in a given country.* A recent Swedish study [Ref. 35] observes for instance that retrievability is an issue that was thought closed about a decade ago, but it may now need to be re-opened based on interest expressed by a number of stakeholders.

Regarding the balance between principles, there are situations (e.g. in medicine) where fairness (informed consent) may take precedence over safety, so "safety first" should not be considered as an *a priori* overriding requirement, but rather as the outcome of a considered judgment. The issues of imposed risks vs. personally accepted risks, and of balancing the needs of society vs. the individual also enter into the decision-making. In addition there is a time dimension, which may involve seeking intergenerational equity without disadvantaging present society (e.g. balancing worker safety vs. future public safety). Since implementation itself can last several generations, the time dimension may apply even during operation.

Because they touch on freedom of choice and its relationship to safety, the concepts of R&R link societal and technical considerations. They tend to be central in the debate on "disposal" when the public and society at large are involved; hence the continued interest in these topics.

2.3 Terminology matters!

The terminology of geological waste disposal varies across different national waste disposal programmes. For example, because of differences in language and because of administrative and historical reasons many countries find that they cannot use the term "safety case" as defined in international guidance.

The nuances that specific terms such as "waste", "disposal", "storage" and "undue burden" may take makes it difficult to be sure that there is a shared vision internationally. Perhaps more critical is the fact that the meaning of terms may be different to different stakeholder participants in the same national programme. A number of examples of such terminological differences were noted in NEA-6869, "More than Just Concrete Realities: The Symbolic Dimension of Radioactive Waste Management" [Ref. 36] as well as in [Ref. 34]. It is important to agree upon the precise meanings of terms to be used. Clearly it can be difficult to reach agreement on statements on reversibility and retrievability, either nationally or internationally, when the participants use the same terms to mean different things.

For clarification purposes, several relevant terms as used throughout this document are defined hereafter. In selecting the meaning of terms, where possible we have followed the terminology used in the *Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management* [Ref. 37] that has been ratified by most OECD countries. These definitions are not necessarily those officially adopted by NEA counties.

Waste

- According to the Joint Convention "radioactive waste is radioactive material … for which no further use is foreseen".
- Not all programmes use the word "waste". This term has negative connotations, implying something dirty or something to be rejected. Therefore there are countries where radioactive waste management (RWM) institutions avoid using this word in their official documents and communications. A more neutral or technological term may be preferred, as *e.g.* in Italian "scorie" (by-products) instead of "rifiuti" (refuse) [Ref. 36].
- In some countries material may be considered to be waste as soon as it is no longer wanted or needed by its owner, perhaps even before it has been packaged for disposal; in other countries, a material is considered to be waste only once it has been emplaced in a repository, or perhaps even not until the repository has been sealed and closed. This difference clearly carries with it implications for the concept of retrievability: what is it that is being planned for potential retrieval?

In this report, we will consider materials to be waste as soon as it is decided by their owner that they are to be emplaced in a deep geological repository. The term "waste" will also be taken to include spent fuel in those programmes where spent fuel is not considered a potential resource and is therefore to be emplaced, eventually, in a repository.

A subsequent decision to consider the materials to be a resource to be made use of would then be one of the possible reasons for deciding to retrieve them; clearly, if this is considered to be more than a remote possibility, retrievability for reasons other than safety must be one of the characteristics of the repository.

Disposal and Storage:

According to the *Joint Convention* **disposal** means the emplacement of radioactive waste in a repository *without the intention* of retrieving it, while **storage** means the holding of radioactive waste in a storage facility *with the express intention* to retrieve it at a later time.

- In many languages there is ambiguity between the terms "storage" and "disposal" and an explicit legal distinction needs to be and is, sometimes, made between them, where "storage" means that the facility is temporary, while in the case of "disposal" the facility is potentially or actually definitive. For example, in France, the Parliament enshrined the reference word for disposal ("stockage") in law. In denotative French*, "stockage"* is a temporary store. In some countries (e.g.

France, Spain) radioactive waste management (especially low- and intermediate-level waste) facilities are called "storage centres" even if there is no intention to retrieve the waste.

- The term "final disposal" is often used, drawing on a connotation of the intent to dispose of the waste and be able to walk away from it. The terminology has been changed recently in several countries to "deep facility", in order not to be seen as precluding activities such as retrievability and monitoring. Terminology was changed in Finland from "final repository" to "repository" for this type of reason. The same is true for Sweden. In Switzerland, the disposal concept is called final, long-term monitored disposal", to signify "final disposal" intentions but with an uncertain end to the period of monitoring and accessibility of the waste.

- In some programmes, such as in Canada, the term disposal is not used at all[2].

- In some programmes, a deep geological facility is still only a storage facility until the final decision is made to seal and close the facility, and only at that time would it become a disposal facility. In effect, the purpose of the facility (storage vs. final disposal) is left undecided, or at least potentially variable, until the time of the closure decision[3]. In other programmes, a facility whose final purpose is permanent disposal may be considered to be a disposal facility as soon as it is constructed.

In this report, in order to be able to compare similar situations in different countries we will use a single interpretation: regardless of the national terminology, a deep geological repository will be considered to be a disposal facility from the beginning of its life, and wastes emplaced in the repository will be considered to have been disposed of. With respect to storage, in the context of this report storage is not considered to be an alternative to disposal; rather it is a step in the management strategy leading to final disposal.

Reversibility, Retrievability and Recoverability

Reversibility describes the ability *in principle* of reversing decisions taken during the progressive implementation of a disposal system. It requires conceiving and managing the implementation process and technologies in such a way as to maintain as much flexibility as possible so that, if needed, reversal of one or more previous decision(s) in repository planning or development may be achievable without unnecessary effort. The implementation of a reversible decision-making approach implies the willingness to reverse or modify previous decisions in the light of new information and a decision-making culture that encourages a questioning attitude.

- "Reversibility" is another concept that has generated heated debate. Some interpret reversibility as a means for facilitating the correction of potential mistakes in the future, which would imply that it primarily addresses uncertainty regarding the long-term safety of waste management facilities. Others, however, argue that reversibility draws on the positive connotation of flexibility

[2] In Canada the term "long-term waste management" is used by the Nuclear Waste Management Organization (NWMO) in order to reflect the evolution of ideas in response to societal expectations. The words "waste management" replaced the words "waste disposal" to reflect a change from an engineering project (design and build a repository) to an ongoing societal process that includes designing and building a repository as only one of the elements of an evolutionary and adaptive process.

[3] In France, for instance, the Law of 28th June, 2006 (art. L.542-1-1) defines disposal as the emplacing of radioactive waste in specially-constructed installations to "preserve" these substances in a fashion that is "potentially definitive"

and freedom of choice provided for future generations. According to this interpretation, reversibility represents a commitment to the values of intergenerational equity and democracy [Ref. 34].

Reversal is the action of undoing a previous decision. Depending on the importance of the latter, *reversal may* require less or more important co-ordination with other interested parties: regulators in the first place and other stakeholders. Indeed, the regulators may mandate the reversal of a technical decision.

Retrievability, in waste disposal, is the ability *in principle* to retrieve whole waste packages once they have been emplaced. Retrievability is the final element of a studied and fully-applied reversibility strategy.

Retrieval is the actual action of recapture of the waste packages, whereas retrievability is the potential for retrieval.

Recoverability: In situations where it is no longer possible to retrieve intact waste packages, it may still be desired to recover the waste materials. Recoverability is the ability *in principle* to recover the waste materials regardless of the presence or otherwise of packaging materials, e.g. by using techniques similar to those used to mine mineral ores.

Finally an important concept is that of **closure**, which is also somewhat variable. In a facility that consists of several galleries or emplacement vaults, some vaults may have the emplacement of wastes completed, and the vault may be backfilled and sealed, while other vaults are still being constructed. After all galleries have been backfilled and sealed, access shafts may be left open for some time. Even after access shafts are closed and sealed, a repository may not be considered officially closed for some period of time while surveillance and institutional control measures continue, and closure may only be considered to have happened when the surveillance and control measures end (if ever). *In this report we will consider closure to take place when the last access shaft is sealed.* It is clear, however, that a repository that is not yet sealed may be seen, during its active operation, as not being fully open but in a situation of partial closure.

Institutional Oversight vs. Control

Control can take place through measures that do not necessarily rely on man. For instance, the barriers that constitute a nuclear waste repository do exercise some types of control functions long after closure of the repository: they control the access of groundwater, the temperature of the near field, the release of radionuclides, etc. These are forms of intrinsic, passive controls. Active controls require instead the presence of a regulator or other oversight organization, e.g., in the form of inspections, verification of records, verification of quality assurance procedure, verification of safeguards, etc. Oversight is the more general term that refers to society “keeping an eye” on the system. Monitoring, if used by regulators to check whether regulations are being met, can be seen as an active control measure; if it used by society to check that the environmental conditions are not degrading, it is an active control measure but under an oversight rather than a regulatory regime. In this sense we may refer to it as an “active oversight” measure. For the time period following closure, when the presence or the role of the regulator is not assured, we consistently use the more general term of “Institutional Oversight” rather than of “Institutional control”, reflecting the fact that the regulation-enforcing aspects may be weaker than in the earlier period (see also Fig. 2 in section 3.2).

3. RETRIEVABILITY AND REVERSIBILITY: IMPLEMENTATION AND CHALLENGES

The mission of a geological repository is to provide protection of man and the environment from any hazard that the radioactive waste would pose over time, without the need for active control and intervention. According to the international Joint Convention’s definitions of waste and disposal, once the waste is emplaced in a final repository, there is no intention to retrieve it. Also, since long-term safety is intended, closing the repository once all the waste is emplaced must be planned for. The final license of a repository is explicitly granted on the judgement that, in principle, no active oversight or intervention are needed in order to assure long-term protection of man and the environment.

Retrievability, if explicitly provided for in the repository design and implementation, reflects a willingness not to preclude the possibility of a future change of intention, but it does not imply a definite expectation that such a change of intention will necessarily take place. Similar considerations apply for reversibility provisions in project management.

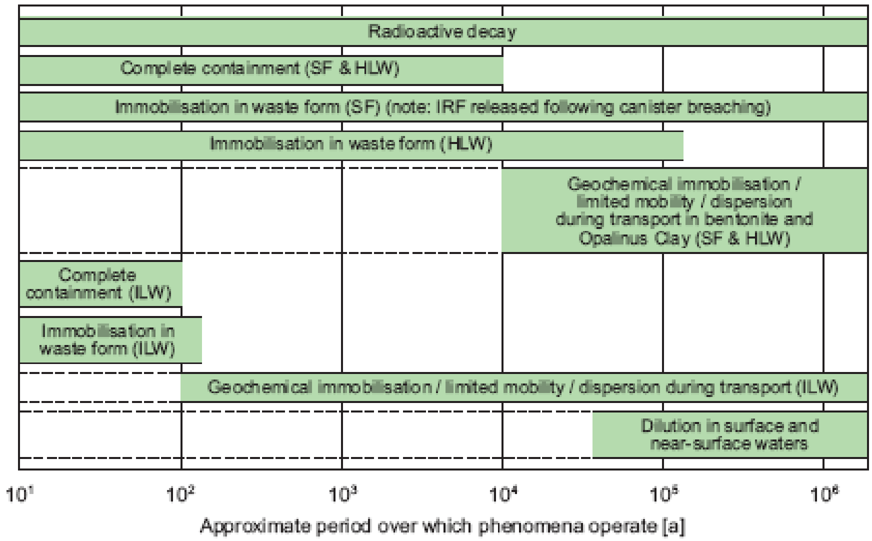
The remainder of this section reviews the main components and design features of a repository and observes which could be provisions that could favour or impede retrievability. Similarly, the implementation of the repository is followed though its various life phases in order to understand what could favour or diminish reversibility. Finally, technical and non-technical factors and challenges in implementing reversibility and retrievability are reviewed.

3.1 Repository design and components vis-à-vis retrievability

The long-term safety of a geological repository is based on the concepts of containment and confinement of the long-lived waste, provided by multiple natural and engineered barriers. This creates a situation in which the waste could potentially be accessed and retrieved or recovered over very long time scales. One example is the safety-case analysis produced by Nagra ([Ref. 38]; see Figure 1), where it is reported that complete containment of the radioactive materials can be expected over a period of 10,000 years or more. Most of the radioactive materials will stay very close to the original emplacement also at later times. Similar conclusions apply to other geological repository designs.

While the design features of geological repositories may vary in different countries, a geological repository for long-lived waste typically comprises nuclear waste forms, containers, emplacement cells with or without buffer materials, repository access ramps or shafts and the surrounding host rock. A horizontal or near-horizontal lay-out is universally implemented. The orientation and layout of the repository must take into account the directions and magnitudes of the relevant rock stresses.

FIGURE 1: Time scales over which relevant phenomena operate (from [Ref. 38])



A brief description of each of the repository components and the impact that waste retrievability may have on them, and vice-versa, is given below.

3.1.1 The waste form

The waste form itself may be a barrier to prevent escape of radionuclides or other hazardous substances. Depending on the robustness of that waste form, its preservation may be an issue to be dealt with during potential retrieval operations. For example, if spent fuel is disposed of directly, the fuel cladding is a barrier to release of radionuclides from the spent fuel. All other things being equal, it would be preferable to preserve this barrier until retrieval is completed; otherwise, fuel particles may be released from the fuel rod into the container, increasing the radiological hazard during retrieval. This may impose constraints on the eventual retrieval process which can have an impact on retrievability design provisions. For some types of fuel, if retrievability is foreseen as an option, this consideration could have an impact on the design of the waste container.

3.1.2 The Waste Container

The waste container serves as an engineered barrier, and is designed to provide safe containment of the waste during a specified design lifetime. The physical configuration of the waste container will depend on the repository concept. However, major parameters that need to be considered in designing the container include: (i) the waste form itself; (ii) container materials compatible with the host media; (iii) mechanical properties of material and mass of container; (iv) radiological protection; and (v) heat output.

One additional parameter to be considered may be the ease of retrieval. In terms of retrievability, long lived waste containers are clearly beneficial for waste retrieval in that the container retains its integrity over a longer period. Container longevity is often achieved by the choice of material, a specific thickness of the container and the control of the emplacement cell environment so as to endure the specified design lifetime. In addition to container integrity, any external handling features of the container ought to be designed to survive any retrievability period, if such a period is imposed. In this regard, materials that resist corrosion over a long period of time are favourable. The robustness of the waste container will need to be sufficient so as to maintain its structural integrity during any preparation processes for retrieval. In some cases, the waste containers are vented to prevent gas pressurization. The possible implication of container vents is considered when there is a possibility that gaseous radionuclides might migrate through the vent leading to contamination of the backfill, which subsequently might affect the retrieval operations. The size and weight of the waste container are also important factors when retrieving waste. Large containers could be more difficult to handle and possibly impose more shielding requirements, but small containers would imply more packages to be retrieved.

3.1.3 Emplacement Cell

Depending on the repository design, an emplacement cell could be a vault, a chamber, or a borehole (vertical or horizontal). In designing an emplacement cell, features that need to be considered include: (i) size of the emplacement cell and capacity, i.e. number of waste containers; (ii) use of buffer between the waste container and the sidewall of the cell; (iii) orientation of the waste container within the placement cell; (iv) the requirement of rock support / lining; and (v) the orientation of the emplacement cell vis-à-vis the prevailing rock stress. To facilitate waste isolation and repository closure, emplacement cells are often backfilled with sealing materials. Typical sealing materials include swelling clay such as bentonite and/or a mixture of clay and sand aggregate. The purpose of sealing the placement cell with low permeability material is to limit the rate of transport of contaminants and also to stabilize the access opening. Just as with the waste container, in some programmes ease of retrieval may be an additional factor to be considered during design

The size of the emplacement cell has implications for retrievability. Shorter cells may require less complex machinery for waste package emplacement and retrieval. However, this provision needs to be balanced against the capacity and footprint of the repository. Materials used in the emplacement cell for retrievability purposes should also be designed to be chemically compatible with the container materials and should not induce any disturbance of the sealing material or host rock.

Repository Access and Repository Lay-out

Repository lay-out and access is also related to retrievability. For example, deep boreholes offer a much more difficult access to emplaced wastes. In fact, this is one reason in some countries (e.g. Sweden; see [Ref. 35]) for rejecting borehole disposal and opting for a more conventional repository.

Access from the surface to the repository level is typically achieved by shafts and/or access ramps. The designs depend on the repository layout, waste inventory, the waste emplacement process and the host rock type. Access openings are often sealed with backfill in order to seal the emplacement cell and also to restrict inadvertent intrusion. For access shafts or ramps that are excavated through aquifers or fracture zones, a barrier to prevent or minimize groundwater ingress is required and must be maintained for as long as the access shaft remains open. If a period of waste retrievability is required for social, political or other reasons, and the access shafts were part of the retrieval concept, all rock support, access drift and shaft linings used must be designed to retain sufficient integrity during that period.

3.1.4 Host Rock

Within the multi-barrier repository system, the host rock acts as a natural barrier to maintain favourable hydrogeological and chemical conditions for long-term isolation of the waste and to protect the repository from disruptive events and human intrusion. The specific characteristics of the host rock will depend on the local geology of the site selected for a repository.

The host rock has implications in terms of retrievability. For instance, some strong competent rocks (e.g. crystalline rock, volcanic tuffs) are self-supporting and minimal engineered support and maintenance is required to prevent failure of the rock walls in the emplacement cells. In such situations waste packages, therefore, may be expected to remain accessible for retrieval without the need for significant additional engineered features during repository construction. On the other hand, argillaceous rock formations in France (Callovo-Oxfordian), Canada (Ordovician argillites) and Switzerland (Opalinus Clay) are consolidated sediments. These and other similar rock formations may have excavation damage zones (EDZs) around excavations in the repository, depending on the rock characteristics. Rock support by means of rock bolts with metallic arches, metallic meshes, shotcrete and/or concrete tunnel linings may be required to provide mechanical stability for a long period of time in order to support retrievability. Salt formations may be even less amenable to retrievability without significant construction features to support it, as salt tends to flow and close around the containers, especially when the latter are heat-emitting.

3.2 Repository Life-phases and Reversibility

The planning and implementation of a geologic repository typically proceeds by an incremental, step-wise approach. Authorizations also tend to be granted via discrete decisions within a licensing process. At each step in such an approach, the decision of whether to proceed to the next step, or to modify the design or the process, is made in light of technical as well as social and political factors and in light of the terms of the license. The step-wise approach provides opportunities for technical, societal and political reviews and, in principle, allows for the building of shared confidence in the feasibility and safety of the facility, as information and experience are acquired and decisions are democratically made. The step-wise approach also allows the process and its decisions to be progressively informed by data obtained through monitoring. The type of monitoring that may be of interest during such a step-wise process leading from construction to closure is currently being developed as part of the EC-sponsored, FP7 “MoDeRn” project (Monitoring Developments for safe repository operation and staged closure [Ref. 39]).

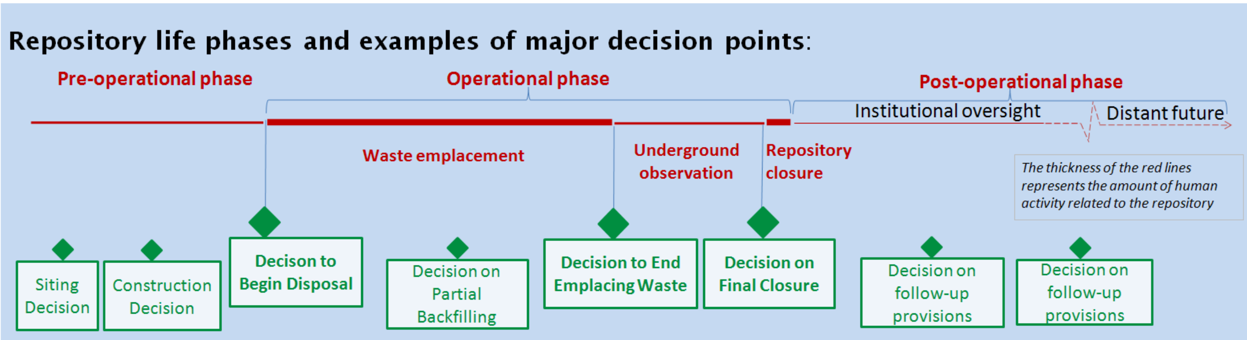
Checking at each stage whether the license conditions were fully fulfilled requires that, if necessary, the license could be amended or even revoked. It has been observed, e.g., by the French Government that “a condition for the acceptability of decisions is reversibility” [Ref. 8]. Likewise, participants in R&R Working Group meetings have suggested that reversibility, at least in the sense that there is a possibility that the decision might be not to proceed, must exist in principle for a regulatory decision to be credible in the eyes of all stakeholders [Ref. 25].

If reversibility is decided upon as a feature of a repository programme, then it would also be necessary to foresee retrievability strategies in the planning, design and implementation of the disposal facility. In particular, it would be necessary to consider what the operations of retrieval and recovery would entail at various stages during the repository life cycle.

During the early stages of a programme, reversal of a decision regarding site selection or the adoption of a particular design option may be considered. At later stages, during construction and operation, or following emplacement of the waste, reversal of a decision could involve the modification of one or more components of the facility, or even the retrieval of waste packages from parts of the facility. However, as repository development proceeds and approaches final closure, going back to earlier phases of the repository life cycle would become increasingly more complex. In all cases, it would require prior authorization from the nuclear regulator upon the submission of a safety case for undertaking it. On the other hand, it could be easier to take decisions resulting in a lesser degree of retrievability if there was a trail of earlier decisions indicating that reversal had been considered but not deemed appropriate.

All geological repository projects involve three main life phases, namely (i) the pre-operational phase, including initial construction prior to the first emplacement of waste; (ii) the operational phase, which includes the emplacement of waste, the pre-closure monitoring and performance confirmation period, if any, and the final closure of the facility; and (iii) the post-operational phase, including possibly a post-closure period of institutional oversight and memory and the distant future after oversight and/or memory cease. Each transition from one phase to the next is typically determined by a specific decision. Figure 2 gives a life cycle overview of the repository throughout the major phases of nuclear waste management.

FIGURE 2: Repository life phases and decision points



3.2.1 Pre-operational Phase

During the pre-operational phase, the site is selected and characterized, the repository is designed, the man-made materials are tested and the engineering demonstrated, the support facilities are built, the licenses for building and operation are applied for and received, and construction begins. A baseline of environmental conditions is also obtained.

The majority of pre-operational activities do not involve significant irreversible actions. Decisions taken during the pre-operational phase may cost both time and money, but these costs would usually be relatively minor compared with the costs of reversal or retrieval during later phases. The most important decisions related to reversibility and retrievability during this phase would be decisions on whether or not to incorporate reversibility and/or retrievability provisions in the design in order to facilitate their implementation during the remaining stages of repository development.

Reversal of decisions during subsequent phases can be facilitated by adopting, during this phase, a stepwise approach to decision-making.

3.2.2 Operational Phase

The operational phase consists of three main stages: (i) the emplacement cell construction and waste emplacement stage; and (ii) the observation stage; (iii) closure of the facility. Interestingly, different parts of a repository may be in different stages at the same time, e.g. construction of new disposal areas may proceed in parallel with emplacement or post-emplacement surveillance and monitoring activities in other areas.

In the waste emplacement stage, the waste packages are emplaced within their immediate engineered barriers. Depending on the waste and host rock characteristics, there are different options for the time at which the various barriers may be put in place. Requirements for waste retrievability, if any, may also affect the options selected. During the waste emplacement stage, the repository is monitored for operational safety. Where an observation stage occurs after waste package emplacement has been completed, the repository would be monitored. The monitoring results would be compared to the baseline data to confirm that emplacement has been carried out in conformity with requirements and, to the extent possible, to ensure that the repository is performing as designed. Research and development continues, and the regulator performs regular reviews of the long-term safety case.

Before closure, retrievability may be considered to be an operational issue or feature, and may be required as part of the performance confirmation process. The ability to retrieve deficient or damaged or non-quality-assured waste packages during the emplacement phase of repository operation may be considered to be one of the features contributing both to operational safety and to assurance of long-term safety, in the latter case by providing the ability to ensure that the assumptions underlying the long-term safety case have been validated and confirmed. During the emplacement phase, retrievals are likely to be rare events and would likely only be carried out for a small number of containers (if any) and only for operational reasons.

During the early stages of waste emplacement, retrieval might be one of the means by which a decision could be reversed. At later operational stages, when a number of packages have been emplaced, but before backfilling and sealing of the disposal cells, retrieval might still be relatively easy, and might involve little more than the reversal of the emplacement process. However, during later parts of the operational period, retrieval would become successively more difficult and costly. This is not only because of the need to reverse more and more actions (e.g. the removal of backfilling material), but also because of the effects of equipment aging and possibly non-favourable evolution, i.e., creep, of the surrounding geological materials.

Depending on the design of a repository, retrievability requirements could result in the repository remaining open for a period of time that could be longer than would be necessary without retrievability. This postponed closure strategy might be considered necessary for a variety of reasons, among them regulatory compliance, thermal management of the waste output or to enable a performance confirmation programme (a monitoring programme to confirm that waste has been emplaced in compliance with design requirements) to be completed, as well as providing an opportunity to build additional societal confidence in the implemented disposal method.

In the closure period, all access ways including shafts will be backfilled and sealed to isolate the repository. The decision to close the repository will depend on a number of factors including technical considerations, societal choices and the implications on safety and safeguards of keeping the repository open.

It is worth noting that postponing closure, for example by postponing final backfilling of access shafts, may ultimately delay the achievement of a favourable situation in which the repository is passively safe and this would be an aspect to be taken into consideration, especially by the regulator(s). The period during which it would be practicable to postpone repository closure without compromising long-term performance may vary for different host rocks and for different repository construction techniques.

It has also been pointed out (e.g. [Ref. 40]) that the use of certain construction techniques during operation, such as the use of tunnel-boring machines for excavation, may facilitate post-closure retrievability. When performing cost-benefit analyses for such techniques, their impact on future retrievability and on such issues as future safeguards concerns should also be taken into account.

3.2.3 Post-operational phase

Following repository closure, waste retrieval or recovery would become significantly more difficult. Some form of mining operation would be required to retrieve waste containers or to recover wastes in the event containers have lost their mechanical integrity.

The post-operational period may begin with a period of formal institutional oversight. It is reasonable to expect that monitoring and surveillance would be maintained for as long as society considers it beneficial, even though it is a characteristic of geological disposal – and part of the basis for the closure license granted by the regulator – that safety does not depend on post-closure monitoring. On the other hand, the fact that all concerned stakeholders have agreed to move to post-closure (in some countries a process formalized by a parliamentary decision) should also mean that no further in-situ data is required for safety. Otherwise, it could be argued that it was premature to move to post-closure. In some programmes, partial closure of parts of a repository may offer an opportunity to monitor conditions in the early post-closure period prior to formal closure of the entire repository.

It should also be noted that any post-closure monitoring decided by future generations should be designed in such way that no significant negative impacts on the performance of the containment barriers and therefore on the long term safety of the repository would occur. Due consideration must therefore be given to reach a balance between what is expected of monitoring and what is technologically feasible. It may possible to obtain in-situ data even after closure. However, such monitoring ambitions will be constrained by limits on the amount and duration of data collection. Surface-based techniques providing data on the macroscopic evolution of the closed repository and ongoing-monitoring in deep boreholes can be carried on, however, as these activities are not technically influenced by the process of closure.

Safeguards controls may continue to apply. Societal memory may continue, and archives and landmarks may record details of the repository or remind future generations of its existence. In the longer term, loss of control and memory might eventually take place, for example through situations of war or anarchy, or as a result of natural events including major climate changes (e.g. glaciations).

After closure of the repository, and even after the end of any period where retrievability might be required post-closure, retrieval of complete containers might still be possible, particularly if the containers were still intact. As long as societal institutions similar to those in place today continued to exist, retrieval, if decided upon, would be a nuclear activity, which would require a permit from the nuclear safety authorities, as would the treatment and storage facilities that would be required to receive any wastes that were retrieved. It might also require research and development and demonstration of feasibility before being approved, particularly if it required new techniques rather than simple reversal of the emplacement techniques. The potential for retrieval (retrievability) would be facilitated if a continuous link with the past existed and information was preserved about how the repository was designed and implemented.

Once the integrity of containers can no longer be relied upon, recovery of the materials by techniques similar to those used in mining would likely still be possible. Maintaining institutional memory of the original design could be one means by which this could be facilitated.

When today’s societal institutions may no longer continue to exist, retrieval or recovery, as well as the management and storage of the recovered waste, would continue to be a major but still possible engineering endeavour. They would be more difficult than during of the period of societal continuity (prior to loss of institutional memory). They would require resolve, resources, and technology, and would probably be a major engineering undertaking. Similar challenges have been faced when deciding and planning to save ancient monuments, such as the Abu Simbel temples dating from the times of the pharaohs. An additional challenge in the case of recovery of radioactive or otherwise hazardous materials from a repository would be the need to construct and operate facilities to manage the recovered materials safely.

3.3 Technical factors and challenges

3.3.1 Factors in Planning for retrievability

The ease of facilitating waste retrieval, if pursued, would depend on (i) the repository concept, barriers and location, (ii) the timescales during which retrievability requirements, if any, might be imposed, and (iii) the stage of repository evolution when the waste retrieval might take place. The practicability of such actions would have to take into account the associated worker safety, mining expenses and other technical requirements. In principle, whether or not the repository has special provisions for waste retrieval, it would be possible to recover waste from closed geological repositories by applying specific mining techniques.

Retrieval and recovery strategies with varying degrees of retrievability are possible. Some considerations that should be taken into account in developing such a strategy are described below:

Repository Life-phase	Retrieval Strategies	Factors to consider
Pre-Operational	<u>Develop a retrieval plan</u> ▪ A well devised retrieval plan is useful in formulating a successful retrieval project. The plan must consider all important factors that could influence the radiological and environmental safety as well as the feasibility .of retrieval. In developing the retrieval plan, changes may occur because of policy shifts,	Important factors to be considered in a retrieval plan include cost, timescales, risk reduction, hazard identification and mitigation, the complexity of the aged waste and waste package, the extent of inventory

	emerging situations, change of process data, etc. There may also be hold points where implementation cannot proceed until the results of previous steps are known. In these cases, a flexible retrieval plan which allows new decisions / circumstances to be incorporated would increase the successful chance of the retrieval operation. Periodic review of the retrieval strategies based on ongoing or phased development work would also increase confidence in the operation	knowledge, the scale of the task (volume to retrieve), and the required downstream processes (repackaging, conditioning, treatment, final waste disposition). Factors of particular interest for the development of retrieval strategies in the pre-operational phase may include the properties of the host rock and specific aspects of repository design such as the degree of backfilling and sealing of repository openings and connection of the repository to the surface. In addition, the timing of retrieval, the delay between waste emplacement and its retrieval may also affect the feasibility and practicability of retrieval.
Operational	<u>Postpone repository closure or partial backfill after waste placement</u> ▪ In such a delayed closure strategy, repository backfill is not emplaced immediately, so that the waste packages remain readily retrievable until the decision is taken to close the repository. ▪ A slight deviation of such strategy envisages partially backfilling the repository after waste emplacement has been completed. This method involves emplacing some engineered barriers, typically the type of engineered barrier that can be removed without major difficulties such as backfilling a filled emplacement cell / room. In such cases, the demonstration of the ability to return to the waste may be required at the date the partial backfilling is decided on. ▪ While this strategy could have the advantages of promoting local employment near the repository site for the prolonged pre-closure period, allowing more time for research and development to be carried out, and also having a higher degree of control over the emplaced waste, the negative impacts of its needs for additional monitoring, safeguards requirement, and institutional controls throughout the time before repository closure cannot be ignored.	The safety implications of such a prolonged pre-closure tactic would have to be evaluated carefully. It could be argued that the impacts on the public and the environment may be lower than would be the case if the facility were closed more rapidly since the facility will remain under active control when the radioactivity of the wastes is highest. On the other hand, with only partial or no engineered barriers emplaced, radiological impacts on human and organisms (flora and fauna) may be higher than they would be from a closed repository. Conventional safety of workers (i.e. likelihood of accidents underground), potential release of toxic materials to the environment, and land requirements (i.e. area that cannot be used for

		other purposes due to the presence of the repository) are also important factors in assessing this strategy.
Post-operational	Apply feasible mining techniques depending on site geology ▪ Many national programs have demonstrated that retrieval or recovery during and following repository closure should be possible, although the process may be significantly more difficult than in the earlier phases. Some form of mining operations would be required to retrieve waste packages or to recover wastes following closure. Retrieval in the post-closure phase would bring further challenges as significant evolution and deterioration would have occurred which may introduce other uncertain situations to arise during the operation. Nevertheless, it is likely that mining techniques involving some form of core drilling and over-tunnelling could be applied should retrieval or recovery be required. Retrieval and recovery methods for this period would mostly depend on site geological characteristics and also on the provisions for management of recovered wastes.	Consider specific site geological characteristics which may limit the applications of various mining techniques.

3.3.2 Technical Challenges in Implementing Retrievability

Provisions favouring the ability to retrieve whole waste packages (retrievability) may bring with them some unavoidable technical challenges in terms of the design of the repository and its associated infrastructures. These implications vary somewhat depending on the repository concepts and locations. Some common technical challenges are discussed below:

Repository Life-phase	**Technical Challenges**
Pre-Operational	▪ Depending on the repository concept, site specific environment, and subsequent degradation processes, the waste container may be subject to particular design requirements such as extra long design life, more robust container design to ensure safe retrieval, and/or the provision of lifting/handling features on the container. In this regard, materials selected must resist corrosion over a long period of time with adequate corrosion allowance, the robustness of the container will need to ensure continued integrity during any preparation processes for retrieval (i.e. during removal of buffer, cleaning or other preparation processes of the emplacement cell), and any handling features provided must survive the retrievability period.
Operational	▪ Waste retrieval during the phase where the emplacement cells are not sealed and the containers are accessible is straightforward. Most technical challenges that may be

	encountered can be resolved by good engineering planning and design, as equipment and machinery used for waste package emplacement can be used for waste package retrieval by reversing the emplacement steps. Successful waste retrieval would therefore depend on the design measures to ensure safe repository operation. In addressing operational safety in a repository, one must realize that retrieval of a waste package entails an additional package handling operation, which may be more or less hazardous than the original emplacement operation. Appropriate radiation shielding in the retrieval operation is considered important. Also, in any period of operation, there are risks associated with fault situations (e.g. loss of electrical power, flooding, rock falls) which may be accompanied by further conventional and radiological hazards. In any case, measures which will reduce the need of manual operating may be advantageous. Measures such as utilization of robust equipment to handle multiple packages so as to reduce worker exposure time, the use of remote handling equipment or the use of sensors to monitor the working environment may help support operational safety within a repository during the retrieval process.
Post-operational	▪ If it were decided to retrieve or recover wastes from a closed repository, new equipment and retrieval methods could become necessary to restore access to the waste packages. The type of equipment required would depend on the concept and materials selected for the repository. To retrieve waste after repository closure, invasive mining approaches would likely be required, and the hazards associated with conventional mining activities would need to be addressed. Particularly in cases where a long period of time had elapsed between emplacement and retrieval or recovery, significant container or emplacement cell degradation might have taken place, new equipment might be required for retrieval (i.e. different equipment to that used for emplacement), and the associated risk for retrieval operations and the safety of equipment operators would need to be evaluated prior to retrieval or recovery. Qualified personnel with the necessary skills and expertise would be needed for carrying out the retrieval operation or operating the retrieval equipment. Under some circumstances, the option of opening new access routes by re-mining might be worth considering. In addition to maintaining the required expertise in future generations, it would also be important to ensure that the relevant information was retained in a format that future generations can use. Ensuring that the required expertise is maintained so as to support potential legitimate waste retrieval or recovery without facilitating undesired human intrusion may pose challenges. ▪ Other more specific technical challenges for recovery after a long period of time may include the unknown physical conditions of the geosphere containing the deteriorated waste packages. The conditions of the biosphere and near-surface geosphere may have undergone significant evolution caused by continuous climatic changes. Just as for retrieval or recovery at earlier stages, the risk for public safety must be evaluated and regulatory and safety requirements must be met prior to determining whether waste recovery would be carried out.

3.3.3 R&D challenges

To support the development and implementation of a geological disposal facility for nuclear waste, research and development work are crucial in acquiring new knowledge as well as to apply learned knowledge to improve the design and development of the repository system and its components. As implementing geological disposal is a long-term project with a number of key phases, various kinds of

R&D activities will be required through the different phases of implementation. Also worth noting in setting out R&D strategy are the R&D activities need to respond to the changing needs of the geological disposal project as it proceeds through different phases of implementation. R&D activities are primarily focused on demonstrating the long-term safety of the repository. If retrievability is one of the possible features of the repository, part of the R&D efforts may apply to retrievability, and some R&D activities are suggested in the table below.

Similar to the technical R&D needs, social science research is also important to support effective, sustained engagement with stakeholders, including society at large as well as local communities during the siting process. Social science research may help planning and implementing effective strategies to engage with the public, which would help building confidence among all parties concerned in delivering a safe long-term solution to nuclear waste management.

Repository Life-phase	**R&D Activities vis-à-vis Retrievability**	**Relevant Challenges**
Pre-Operational	▪ During the initial period of the pre-operational phase when the site is selected and characterized, the research and development work required to support the site preparatory and investigation phase would focus on providing the necessary support of data and understanding of processes for the development of conceptual designs and associated safety assessment for a range of potentially suitable geological settings. ▪ With respect to retrieval of waste, preparatory R&D activities could include the development of tools and techniques for demonstrating feasible waste retrieval. Specific design provisions (e.g. deposition machines with retrievability design functions, placement room layout facilitating easy retrieval and/or removable barriers to allow access) may be evaluated in the preliminary R&D program. R&D activities would focus on the methods / processes that will allow retrieval of the emplaced waste at various life phases, while demonstrating that the presence of such specific retrievability provisions will not detract from the performance of the repository may also require R&D. ▪ The objective of the R&D work in this initial period would be to support the safety assessment of the repository as well as to enhance public confidence in disposal. ▪ Any preparatory R&D required for site investigations, including the development of tools and techniques for assessing site-specific information would be undertaken in this phase. In conducting site-specific investigations to evaluate candidate sites,	▪ In conducting preliminary R&D work in the initial phase without detailed site-specific geological information, a key challenge would be to ensure that the R&D work program is designed to take account of the potential physical and chemical characteristics of the host rock as well as possible mechanisms for deterioration of the barriers. ▪ As the timescale for practicability of retrieval (on technical grounds) may be as long as hundreds of years, taking into account advances in technology that may affect the actual retrieval operation would pose another challenge in planning for R&D work activities. R&D on information storage and retrieval on these time scales may also be necessary.

	R&D activities would focus on the processes that will determine the performance of engineered barriers or control the movement of fluids and radionuclides. The objective of the R&D work in this initial period would be to support the development of engineering designs and safety assessment that take account of the physical and chemical characteristics of the host rock and groundwater system present at the site. ▪ As the project progresses to the construction phase, underground investigations in the selected host rock geology would provide the site-specific geological information required for the construction of the facility. R&D in this phase is also expected to support the development of designs for backfilling and sealing systems that will be required in closing the facility safety at a later stage. More detailed assessments of the specific retrievability provisions and the provided engineered barriers (e.g. removable backfill) would be further studied and tested.	
Operational	▪ Once the repository has started operating, the research and development activity is expected to focus on monitoring the behaviour of the engineered and natural barriers in the repository system for comparison with the results of predictive modelling. Extensive R&D on waste retrieval is not anticipated in this phase but potential improvements that may enhance the retrieval operations may be evaluated (e.g. the timescale of backfilling and sealing the emplacement rooms / access shafts). New technologies would continue to be evaluated to ensure waste retrieval, if required, would be carried out in the most effective manner. ▪ Public views on nuclear waste management and also waste retrieval may change from one generation to another. Aside from technical research, R&D on social science is also important to verify the true understanding of how the public perceive nuclear activities or future utilization of the emplaced waste. Both technical and social R&D in this phase would support decision-making on the timescale of sealing and closing parts of or the entire facility. A key objective in this phase would be to identify and implement any improvements that can	▪ While some R&D activities would be intended to respond to social drivers and public concerns, new knowledge acquired from social research may complicate the retrievability options already studied. One potential downside of this is that the more work that is done on enhancing retrievability, the greater is the danger of reinforcing the perception that retrieval will be necessary.

	be required in various aspects of the repository design or operation. R&D in this phase will also support decision-making on the timescale of backfilling and sealing of parts of, and eventually the entire, facility.	
Post-Operational	▪ When the repository has reached the closure stage, it is now at the time at which the facility is in a passively safe mode. Supporting development work would continue during this period with an important focus on supporting monitoring arrangements to meet the requirements identified by the regulators and the host community. The main goal of R&D would be to provide confidence that the repository will perform as designed and long-term safety will be achieved. Technical R&D needs on waste retrieval during this phase are likely to be minimal as viable retrieval work plans would already have been devised. However, as new technologies continue to evolve, the R&D focus in this stage may be on applying the latest technologies to enhancing retrieval safety (e.g. devices or technology to locate shifted or deteriorated containers). ▪ Depending on the prevailing socio-political environment, certain social research work may need to be maintained in order to sustain stakeholder support. ▪ Research may also continue on aspects related to memory preservation, such as knowledge transfer, durability of archives, passive markers, etc.	▪ As above, conducting a balanced and effectively designed social research program is likely to be challenging.

Identifying, Scheduling and Prioritizing R&D

Research and development is part of a process to fill information gaps - the gap between our current knowledge and that which we need to acquire to support the development of the repository. Consistent with the above suggested R&D activities, the overall goal of carrying out R&D work is to improve our knowledge in the decision-making process so as to gain confidence in the design and safe operation of the geological repository. Note that the study of an R&D topic may often affect more than one repository components / systems. For instance, the mechanical and chemical properties of the sealing system may not only directly impact the safe isolation of the container; it may also affect the survival growth rate of the surrounding microbes and therefore subsequently may affect the retrievability of the emplaced container. In planning an R&D task, one should take account of the overall impact of the R&D topic and the timeframe at which the R&D task may affect the overall outcome. Factoring time considerations into the

R&D planning process is particularly important in long-term demonstration experiments as they may run for timescales of decades. In prioritizing R&D tasks, it is important to evaluate the significance or potential impact of the information gap particularly on the design outcomes and safe operation of the repository. Issues that have a significant potential impact on delivery of a safe geological disposal facility should have the highest priority, particularly where there is a large information gap in our existing knowledge and understanding. For R&D areas that require significant resources and/or established technologies, collaborating with other national nuclear waste management institutes may allow efficient use of the best available technologies and resources. Such knowledge sharing not only encourages independent verification of the study result; it may also create the necessary synergies needed for the identifying further research priorities and strategic directions. The lowest priority R&D needs are typically the ones associated with issues that do not have a significant impact on delivery, and in addition, where there is a relatively small information gap. As new technologies continue to emerge, a periodic review of the R&D program to ensure that the existing knowledge remains up to date and no new uncertainties are identified would allow effective use of available resources and budget.

An important question to be resolved in each programme relates to the level of resources to be allocated to R&D on reversibility and retrievability at various stages of development. Programmes in which retrievability is a requirement will have different needs from programmes in which it is optional.

The motivation for research programmes must also be taken into account. Is the research carried out to improve acceptability, to support repository operation, or to allow for flexibility? It is desirable that research should always support safety, and not be done purely in order to improve stakeholder acceptance. On the other hand, research and development that is triggered by stakeholder requests should be integrated into the developer's overall programme and not seen and undertaken as simply an add-on.

It must also be recognized that retrievability is only one small part of the overall design and development process. A strategic decision is needed during the repository development process as to whether efforts should be focused on retrieval methodologies from an unmodified repository design, or on modifications to the design in order to facilitate later retrieval.

Decisions on the type and extent of research may also correlate with a stepwise decision-making process. Depending on the stage currently under consideration, the research and development needs will differ.

3.4 Other factors and challenges

3.4.1 Safeguards – Physical protection

The Treaty on the Non-Proliferation of Nuclear Weapons requires safeguards measures for spent fuel and/or other nuclear material disposed of in a repository until the nuclear material is practicably irretrievable [Ref. 41].

Prior to closure, and even in the absence of any retrievability requirements, active safeguards measures equivalent to those in place at other nuclear facilities, including a relevant physical protection system and nuclear material accountability, will be required. The requirements for material and design accounting to support safeguards may also help to support retrievability, and in this sense the record-keeping requirements for retrievability and safeguards might be considered to be complementary. Even after backfilling and closure, the continued requirement on nations to be able to assure non-proliferation may result in the need for monitoring for institutional control and possible retrieval of the waste. These record-keeping requirements may be complementary to the monitoring and institutional control measures that would support continued retrievability post-closure, even if retrieval is not intended. Nevertheless, the ultimate goal of safeguards after closure is, like the ultimate goal of disposal, not to retrieve the materials, but rather to continue to isolate them from access and contact with persons and the environment, which is, of course, in opposition to the concept of retrievability.

Providing a retrievability period after emplacement operations will require that safeguards measures be maintained continuously for the surface and the underground facilities during that period. Typically, the required safeguards provisions will depend on the ease of access to the nuclear material and the ease of retrieval, while the level of physical protection required will likely be comparable to the level required at an interim storage facility or at a near surface facility. To design for waste retrieval, the following aspects need to be considered:

(i). A repository that stays open to facilitate retrieval will prolong a need of the facility and nuclear material physical protection and the safeguards inspection period. The amount of effort required to maintain an underground inspection regime, safeguards inspection program as well as underground monitoring systems may be significant. A prolonged period of repository inspection also leads to longer underground occupancy times for safeguards inspectors which in turn may result in additional radiation exposure for both the inspectors and repository operators.

(ii). As long as the repository remains open, there may be greater potential for diversion of nuclear material if physical protection and institutional controls are not maintained. Hence, from the safeguards point of view, the extended time for retrieval may be less effective than if closure occurs immediately after completion of the waste emplacement;

(iii). Safeguards measures must be flexible enough to respond to changing technological developments and to changing needs of today’s and future generations. An effective application of safeguards shall assure continuity-of-knowledge that the nuclear material in the repository will not be diverted for an unknown purpose.

Although it is not possible to predict whether a future generation will decide upon retrieval, it may still be possible to take actions during design and implementation of a repository that would facilitate future retrieval, or at least avoid unnecessarily increasing its difficulty. Typically these may include a shorter or longer pre-closure observation phase, monitoring and surveillance and record-keeping after closure, or longer container lifetimes once the waste is emplaced. These can be seen as means by which present generations respect the ethical responsibility to provide freedom of choice of future generations to make decisions different from our own. This responsibility, however, must not be met at the expense of meeting the ethical responsibility to protect the health and safety of both present and future generations. Resolution of the tension between these two guiding principles depends upon many factors, i.e. there is no one “best” way. Clarity on the relative priorities of these two responsibilities is important.

3.4.2 Cost

The costs associated with allowing waste retrieval from a repository may be categorized as follows:

(i). Costs for upgraded repository components as may be required to facilitate waste retrieval. E.g. enhanced containers, emplacement room / cell / vault designs, reinforcement of the underground facilities for long term stability during the retrievable period.

(ii). Costs for monitoring and maintenance during the extended operational period to ensure safety. E.g. maintenance and repairs of equipment / vehicles, groundwater management, provisions for abnormal situations including emergency preparedness, staffing required to maintain safe conditions, security of the repository; and safeguards provision (as discussed in Section 4.4).

(iii). Costs for waste retrieval when it is to occur. E.g. retrieval machinery and operator costs, additional costs for radiation and contamination controls during the retrieval operation and costs for operating interim storage and possible processing areas for the retrieved waste. Also, depending on the stage at which waste retrieval is to occur, additional cost for dewatering the repository and for the management of secondary wastes may incur (note: secondary wastes may include saturated sealing materials or groundwater containing radionuclides).

(iv). Costs for managing secondary wastes, residual contamination and remedial actions. E.g Storage and processing space may be required to manage secondary wastes, such as overlying materials excavated during the retrieval process. Remediation of environmental impacts may also be required.

The costs associated with retrieval operations should also include those related to secondary waste management and additional processing and storage facilities. It should be noted that 'bundling' of costs associated with both development of a repository and ensuring retrievability could make it difficult to identify separately the costs of a requirement for retrievability. There are many factors influencing the cost of retrievability, including repository design, the volume of waste, and the timescale during which retrievability is required. It is seen as important to recognise not just costs of retrieval of waste but also those of new nuclear installations to process retrieved waste and its packaging, and those of alternative repositories for the waste. The costs of retrieval are likely to be comparable in magnitude with those of repository construction and operation.

The question of responsibility for costs is also important. There is a need to distinguish between costs that are the responsibility of the original owner, and those that are the responsibility of the eventual retriever of the wastes. Generally speaking, those costs that support the safety case are considered to be the responsibility of the original owner, but costs for provisions that do not support safety, and are only there to support retrievability, are more contentious. It is difficult to determine where to draw the line between good engineering practice that would have been followed even without retrievability, vs. costs that are incurred solely to support possible retrieval.

When considering whether retrievability post-closure should be a requirement, it is important to be aware of the costs, not only of retrieval, but also of establishing and operating new facilities to deal with the recovered material, possibly including re-disposal. It must be remembered that retrieval is not the end-point. It should also be kept in mind that retrieval is likely to cost just as much as, if not more than, the original disposal, and that regardless of which organizations are directly responsible for costs, in the end it is the public, whether as consumers of nuclear energy or as taxpayers, that will ultimately bear these costs.

The cost of implementing a retrievability option will depend on the repository design, the amount of waste to be disposed (and potentially retrieved) and the timescales over which the ability to retrieve waste is required. In particular, the implementation of a retrievability option could substantially increase the repository life cycle costs if an extended period of repository operations is required beyond the timescales needed for waste emplacement. Finally, it is likely that retrievability provisions will be more costly if implemented later-on in the design, rather than from the start.

3.4.3 Institutional Oversight and Monitoring

One component of demands for retrievability post-closure is a desire for continuing institutional oversight beyond the period during which there is access to the repository or to parts of the repository This may be based partly on a perceived need for further confirmation that the repository is operating as planned, and partly on a concept of safety which includes oversight as an essential component. In this view, the assurance of safety depends not only on predictive demonstrations, but also on continued oversight and monitoring. According to this approach, while post-closure safety assessments are required to demonstrate safety even in the absence of oversight and monitoring, the overall safety provisions would nevertheless include plans for continued institutional oversight, monitoring, and possibly retrievability for a period of time following closure and sealing of the repository.

Institutional control consists of those actions, mechanisms and/or arrangements implemented in order to maintain control or knowledge of a waste management site after project closure and to inform current and future generations of hazards and risks. Any discussion of retrieval or recovery of wastes following closure would likely involve consideration of institutional controls already in place prior to the decision to retrieve or recover. Typically, controls may be classified as follows:

(i). Structural controls which include features constructed to control access (e.g. fences; gates; engineered covers) and physical devices (e.g. signs and monuments to warn of dangers or restrictions).
(ii). Non-Structural controls which include mechanisms that rely on legal and administrative initiatives (e.g., security, preventive maintenance, inspections, vegetative buffer zones, materials labelling, materials handling improvements, hunting licenses or permits, training on radiation safety, and best management practices).

An alternative classification scheme relates to the activities involved rather than to the physical nature of the controls:

(iii). Active oversight measures rely on the significant presence of humans to fulfil safeguard and maintenance responsibilities (e.g., security guards to monitor and control site access; airspace restrictions, environmental sampling to monitor contaminant migration; site inspection maintenance).
(iv). Passive controls are designed to warn and inform future generations about the nature and location of site hazards without significant human intervention (e.g. permanent markers and monuments; barriers such as earthen berms; and oversight methods such as maintenance of public records and archives, and land or resource use restrictions).

Planning for the possibility of future retrieval or recovery will involve planning for institutional oversight in support of future decision-making. When planning for institutional oversight, the use of a graded approach or tailoring controls will allow specific site factors (e.g. site history, local or regional cultural characteristics, input from stakeholders, etc) to be considered, which enables the implemented controls to be flexible to address unique site features. To assure their effectiveness, institutional oversight measures should be designed to adapt to changes over time so as to ensure that the controls and their maintenance can be sustained in the future.

Institutional oversight measures such as knowledge management and memory keeping are important components of institutional control supporting also post-closure retrievability. It should be recognized that the range of situations in which memory can be lost is quite broad. There are recent examples of disruptions in institutional continuity that could lead to failure of institutional controls (e.g. the breakup of the former Soviet Union).

Institutional controls are most often counted upon to reduce the likelihood of inadvertent intrusion, as well as in support of non-proliferation safeguards. Because of the likelihood of eventual loss of memory, inadvertent intrusion is one of the scenarios that are usually addressed in safety cases. Retrievability provisions are intended to facilitate intentional intrusion in order to recover wastes, while not increasing the likelihood of unintentional intrusion. Institutional controls may play a role in achieving this dual mission.

While active memory keeping, relying on land-use records, archives and markers, may not depend on monitoring, memory keeping may also be seen as requiring the availability of ongoing current information about the repository. This leads to the difficult question of how to provide such information. There may be a larger need to support continued development of remote monitoring techniques in those programmes that incorporate post-closure retrievability.

Cost is an important factor in selecting institutional controls. Cost estimates for institutional controls will vary from site to site and are affected by factors such as (i) type of institutional control used; (ii) site characteristics; (iii) need for and frequency of inspections and maintenance; (iv) length of time institutional controls needs to be effective; and (v) level of cooperation with other government agencies (e.g. local law enforcement). A balance needs to be struck, taking into account both the technical and societal values of monitoring and oversight. Decisions need to be taken on what is to be monitored, how is the monitoring to be conducted and for how long it will continue, and cost is clearly a significant factor.

The rigor of the institutional controls needs to be commensurate with the associated hazards. Institutional controls are often prioritized based on their potential effectiveness and consequences of failure, e.g. such that a primary group of controls serves the function of providing primary protection and a secondary group is used to provide backup protection should the primary control fail. In situations where the consequences of loss of institutional controls are expected to be small, the need for redundant controls could be minimal.

Eventually, it may be necessary to replace, modify, or terminate the controls. Procedures should be established for modifying or terminating institutional controls when warranted. The procedures should (i) provide the basis for the decision that existing institutional controls need to be modified or enhanced, or that the institutional controls are no longer required and can be terminated; and (ii) identify the modifications or enhancements to be made and how these modifications will serve to protect human health and the environment.

Monitoring

Monitoring is important not only before closure, in support of stepwise decision-making during repository development, but also after closure. This topic is currently being further developed within the EC sponsored FP7 project "MoDeRn" (Monitoring Developments for safe Repository Operation and staged closure, www.modern-fp7.eu), including both programmatic and sociological considerations of expectations and potential added value as well as considerations of technical feasibility and limitations. Before closure, monitoring is a normal and expected part of the engineered development process, regardless of whether a programme incorporates reversibility and retrievability or not. In addition to monitoring that would be expected in any project, monitoring is also performed to fulfil performance confirmation requirements for a repository. There may be substantial interest from sectors of the public in information that can be obtained from monitoring prior to closure. This may include information of direct interest to performance confirmation, and information of "intuitive" interest (e.g. monitoring radionuclide concentrations in the repository and in the surface environment), in addition to the general public interest in obtaining transparent and traceable information based on in-situ evidence.

Since post-closure safety cases must provide assurance of safety even in the absence of institutional control, monitoring after closure is not part of post-closure safety assessments, but the provision of post-closure monitoring may still be an important component of building confidence and trust. Public concerns about monitoring may continue during the post-closure stage. It is important to communicate the distinction between the ability of the safety case to demonstrate safety in the absence of monitoring and institutional control vs. the intention whether to terminate monitoring and institutional oversight or to continue them after closure, either for a specified period or indefinitely.

There is a significant variety of data that can be made available during pre-closure monitoring, and technical work on monitoring techniques continues. Research and development into monitoring techniques can improve the robustness and lifetime of instruments and improve the capability to measure important parameters. Such work can be expected to take place in all programmes, independently of whether reversibility is required or not.

If retrievability after closure is considered a requirement, there are significant questions that must be answered about the ability of monitoring to supply the information that would be required to support decisions on whether or not to retrieve. While environmental monitoring will likely be required for acceptance and confidence in safety, it is unlikely that remote environmental monitoring will provide useful information about the evolution of a deep geological repository during the timeframes envisaged for monitoring.

Post closure monitoring and institutional oversight are also linked to responsibility for the waste and for safety. In this respect, it should be noted that normally the regulator's responsibility terminates with the end of licensing, which is often coincident with closure. In some countries responsibilities after the repository closure are formally or legally defined (e.g. in Spain, the responsibility of the repository once closed falls on the government, by law), but in others this issue remains open.

Monitoring and institutional oversight are subjects that are expected to undergo continued development. There is a significant societal dimension to these topics.

3.5 Technical Factors that may either Promote or Challenge Retrievability and Reversibility

Geological disposal aims to provide a permanent and safe, long term management solution for radioactive waste. It is universally accepted that repositories should be designed so that safety does not depend on retrieval capabilities of the future generations and that only materials that are declared as being "waste" should be disposed of.

This section summarizes some of the potential benefits and shortcomings of retrievability in the context of the deep geological disposal of radioactive waste. These identified benefits and shortcomings of retrievability may not be comprehensive and the applicability of each advantage or disadvantage may vary between repository concepts. Their economic, technical, ethical or socio-political nature may also be different due to the specific issues of the waste management programme. Benefits or shortcomings must be assessed prior to the adoption of retrievability provisions during the development of the disposal strategy.

Repository Life-phase	Benefits	Potential Shortcomings
Pre-Operational	▪ In some concepts for repositories with retrievability, it is envisaged that the ability to retrieve waste may play a major role in gaining public acceptance. Retrievability of the waste is thus being viewed as a positive aspect as it allows an action or a decision to be reconsidered and possibly reversed. Retrievability may be seen as a means of ensuring continued control, thus contributing to the perception of safety and to acceptance of a proposed repository project.	▪ Although retrievability can be an important factor in public and political acceptance for the siting of repositories, additional delays and costs may be incurred as a result of provisions for waste retrieval. Also, the issue of safeguards and environmental safety considerations must be evaluated and balanced against the public acceptance benefits, as enhancing the retrievability of nuclear waste should not compromise long term environmental safety of the repositories, nor unduly delay the assurance of long-term safety. In some contexts, retrievability may also be viewed by some stakeholders as prejudicial to safety.
Operational	▪ During the operational phase, being able to retrieve waste enables a precautionary approach in waste deposition. Retrievability of the waste allows corrective actions to be taken in cases where there are shortfalls in performance of the repository system or if decisions were considered erroneous. Moreover, provision for waste retrieval also allows technological flexibility in a stepwise decision-making process, which is important when taking decisions for complicated actions. Retrievability of the waste overall is a positive aspect as it allows future generations the possibility to take control of the management of the waste. Particularly among segments of the public, many believe that scientific developments may facilitate the potential future utilization of perceived resources such as plutonium and/or uranium in the spent nuclear fuel.	▪ On the other hand, in safeguards considerations as a result of the existence of the plutonium in spent fuel, retrievability of the waste is a negative aspect as it makes it easier to mine the repository for nuclear weapons material. In situations where a repository is extending its operational period to facilitate the potential retrieval of waste, uncertainties regarding the timing of closure may complicate the development of an acceptable safety case. Long-term safety may be affected if the engineered barriers degrade. The associated costs and risks to workers for prolonged operations will also increase. In ethical considerations of the management of nuclear waste, the need for long term surveillance may also impose additional burdens on future generations. Unstable socio-economic and political situations, which are often unpredictable, may lead to the abandonment of a facility prior to closure with negative implications in terms of long-term safety.
Post-Operational	▪ Geological repositories could be a source of large quantities of	▪ Despite the potential uses of these resources, the present generation that

	plutonium and other potentially valuable elements, such as copper and iron, even when they have been sealed for a long time. Scientific advances and changes in social needs may provide incentives for recovery of spent fuel for energy generation or as sources of other minerals.	produces waste must ensure safe management of nuclear waste, limit burdens on future generations and ensure no significant impact from radionuclides entering the environment.

4. DECISION-MAKING FOR RETRIEVABILITY AND REVERSIBILITY

4.1 Stepwise Decision-Making

In long-term radioactive waste management, consideration is increasingly being given to concepts such as "stepwise decision-making" and "adaptive staging" in which the public is to be involved in the review and planning of developments. The key feature of these concepts is development by steps or stages that are reversible, within the limits of practicability. This is designed to provide reassurance that decisions can be reversed if experience shows them to have adverse or unwanted effects. However, it is important not to use a stepwise or adaptive process as an excuse for delaying decisions, particularly in cases where such delays could have negative impacts on future safety.

In a stepwise procedure, sustainability and efficiency often contradict when decisions are to be made about the size and timing of steps. Often, the smaller the individual steps, the better the chances for social acceptability. Since society is a complex system with many unknown relationships among its components, it can be assumed that in the case of smaller steps, the number of affected components as well as the magnitude of effects will be smaller, and thus the chance for unpredictable responses will be reduced. It is also important that sufficient time be allowed after each step so that the system can respond to the intervention and its consequences can be identified. However, an increase in the number of steps and the intervals between them will also increase the duration and costs of the decision-making process and in some cases may result in additional risks being imposed between steps. Trade-offs between social sustainability of the process and efficiency must be carefully evaluated in designing a stepwise process.

Repository development requires a sustainable relationship between a repository programme and its host communities because of the long time scale for development. There are many decision points along the path of programme development. In a stepwise process, one of the features of decision-making at each stage is a reconsideration of whether to confirm the previous small step and proceed with the next one. Taking these decisions in concert with appropriate stakeholders at each step helps to build a durable relationship between the programme and communities. By keeping previous decisions "alive" in memory through repeated reconsideration and reaffirmation, the process of making the next decision at each step is made less overwhelming [Ref 21].

It was noted in the analysis by the working group of questionnaire responses that many programmes do not yet have processes for stepwise decision-making worked out in detail, nor an outlined methodology and principles for stepwise decision-making and related public consultation, even in cases where a stepwise approach is national policy. It was felt that this is not necessarily a negative observation - designing a detailed process too far in advance of when it will be used is probably not appropriate. The general principles should, however, be clear from the beginning.

The relationships between an implementer's decision-making, regulatory decision-making and societal decision-making are of interest. The basis for the regulatory process is not necessarily the same as for a flexible stepwise decision-making process. The steps in typical licensing processes are very broad, and may limit the steps that are possible during implementation. For example, a proposal to dispose of a small fraction of the wastes and wait for several decades before proceeding with the rest of the wastes might not fit within the normal series of licensing decisions. On the other hand, it must be recognized that there is more to regulatory oversight than licensing, and that the day-to-day regulatory oversight process can be compatible with a flexible process involving many small steps.

The existence of multiple regulators or decision-making bodies also complicates the decision-making process. It is important to keep dialogue and negotiation open among all parties, and not to become too tied down to a fixed framework for decision-making. However, this must be done in a way that respects the need for independence of the regulators. It is also important to avoid “group-think” and to ensure that the overall goal of public safety is always kept in mind and that third party interests are accommodated in the process.

4.2 Reversibility and Authorizations for Repository Development

At one time disposal was often treated as if it were a relatively short-lived activity to be completed in the timespan of perhaps a single generation – the goal being to provide a facility that could safely contain radioactive waste without any further action or intervention by future generations. Increasingly, the implementation of a disposal project has come to be viewed as an incremental process, in a series of successive steps, likely taking several decades to complete. Besides the concept of protection of future generations, this changing vision incorporates as well an assumption of the involvement of the succeeding generations in the process and a need to preserve as much as practicable their ability to exercise choice. As a result of this evolution, monitoring and surveillance are now activities under consideration after closure of the facility.

In its various forms (adaptive phased management, adaptive staged management, phased geological disposal, reversible disposal, …), stepwise decision-making in geological disposal represents an approach to making a gradual transition over one or more generations, from active assurance of safety (interim storage) to passive safety (final disposal with no requirement to retrieve the waste). As part of a stepwise decision-making process, it may be considered that the possibility should exist to reverse or revise previous individual decisions along the way, for example in the light of knowledge gained or of changing capabilities. Thus, stepwise decision-making may bring with it a need for some degree of reversibility, including retrievability, at least up to the point of final closure if not beyond. Stepwise decision-making forms an important part of the context for a study of reversibility and its expressions in retrievability and recoverability provisions.

Reversibility refers to the possibility of reconsideration of one or a series of steps at various stages of a program. This involves a review of earlier decisions with the appropriate stakeholders and requires that the necessary means to reverse a step be available. Reversibility also denotes that, when practical, fallback positions may be incorporated both in the long-term waste management policy and in the actual technical program. Not all steps or decisions, however, need be or, indeed, can be fully reversible. Certain decisions can be used in the process as hold points for programme review and confirmation. Reversibility may therefore be considered to be a way to close down options in a considered manner [Ref. 21], while still respecting the need to take decisions in a timely fashion. If the need to reverse or change course is carefully evaluated with appropriate stakeholders at each successive stage of development of a facility; a higher level of confidence may be achieved, by the time a final closure decision is to be taken, that there are no technical or social reasons to delay the final decision, or to undertake waste retrieval at that time or subsequently. However, in order to embark successfully on a logic of reversibility in waste disposal, it is important to ensure that the decision-making at each step is not used as an excuse for unnecessarily delaying the process. It is also important to clarify ahead of time the principles or values that should be followed in such decision-making steps, and their importance relative to one another.

Regulatory Control (authorizations)

As described in an NEA study of regulation of waste management [Ref. 42], in a broad sense the regulatory control process for radioactive waste management includes not only the process of formal control by a nuclear safety and/or environmental safety regulator, but also the wider processes related to political and societal decision-making regarding waste management strategies and projects. This process often starts with the development of a policy. In nuclear waste management, radiation protection is usually a major component of the policy, since its ultimate objective is to preserve the safety of the public and the environment. Following the establishment of the policy is the creation of legislation. In the development of legislation, standards and guidelines are sometimes published to provide legal details. As an example, countries such as Germany, United States and Hungary, the nature of legislation is highly detailed and addresses wider issues whereas in some other countries, technical standards for radioactive waste management are defined by the technical authorities responsible for implementing and enforcing the law, rather than in the legislation itself [Ref. 42].

With respect to the pre-closure activities related to repository development, just as with other activities involving radioactive materials, consent to act within the bounds of legislation and regulation is generally by way of some formal, legal instrument such as a licence, a permit, or authorization. These documents typically contain detailed terms and conditions and are issued to the person or company that is recognized legally as the operator of a process or activity subject to regulation. In some cases a licence may cover all aspects of regulation related to the regulated process, from initial planning and development, through matters such as occupational health and safety of workers and accident prevention, to the final act of disposal. In other cases they may address aspects separately but having regard to the interactions between them. Compliance with the terms and conditions of a licence is then checked by inspection and monitoring of the operator’s activities. Cases of non-compliance are often dealt with by way of notices or requirements placed on the operator. If necessary, non-compliance is subject to some form of enforcement action. To evaluate the overall success of the regulatory system in meeting the objectives of policy, reviews are often arranged and if necessary, corrective action may be taken during the licensing stage, where terms and conditions of the licence may be modified. In addition to such corrective action, most regulatory systems have the capacity to follow up the granting of a licence to ensure that safe performance is actually being achieved, which includes taking remedial action if necessary.

Different countries have different arrangements for implementation and enforcement of the law. In some countries such as Belgium and Finland, one technical authority deals with the licensing, inspection and enforcement of on-site occupational health and safety matters and of waste disposal, while other technical authorities deal with siting and development of disposal facilities. In other countries such as Germany and the United States, the Federal States have responsibilities of their own, e.g. a State Licensing Authority may issue a license but not take any repository supervision role. Regardless of the variations, these technical authorities often consult other parties with relevant interests or responsibilities before reaching a decision. In regard to licensing, there is usually a mandatory requirement for consultation with, or reference to, other bodies. In many cases there is a legally established system of public consultation during the licensing process, and the observations collected from the public consultation are taken into account when a decision is issued.

Overall, a policy of openness towards the general public is a basic feature of modern regulatory frameworks. Its implementation has become a more and more important task in recent years highlighting changes in the perception and role of the regulator.

There are formal licensing actions at steps such as siting, construction, operation, and closure, but not necessarily at various other points such as partial emplacements, backfillings, etc. Nevertheless, these actions might be considered to be key points that would be submitted in any case to regulatory review, either through the terms and conditions of the authorization or being considered as “significant modifications”, requiring a licensing decision. If as a consequence of stepwise decision-making there is a significant change, e.g. backfilling that makes retrieval more difficult, the regulator would need to be involved, i.e. a staged process would also involve staged authorizations even if the licensing process was not explicitly staged. For example, in the US any condition that would substantially affect the retrievability of waste prior to closure would require a licence amendment.

Prior to closure, for operational safety the regulator may demand that there always be a safe position to return to in case of problems. For practical purposes, this would imply that retrievability of packages is an operational requirement during the emplacement phase. On the other hand, the internationally accepted safety principles require that a final repository must not require societal control, including retrievability. Therefore although it is expected that regulators could require retrievability pre-closure, post-closure they may not unless retrievability is a legal requirement. Even in programmes where retrievability is not a requirement, it need not necessarily be prevented. Although closure cannot be approved until the regulator is certain that disposal is the right option and safety is assured, after closure, the logic of retrievability may suggest that the design should not make it unnecessarily difficult to retrieve. However, this is outside the original regulatory remit.

One point of interest relates to delayed closure. If decision-making and retrievability requirements lead to a delay in sealing or backfilling galleries, there might be an impact on safety. Therefore the regulator needs to be involved in any such decisions, preferably from an early stage when such delays may be considered or planned as part of the development process (e.g. in a “flexible” or “adaptive” staged process).

At each step in the entire decision-making process, a decision to proceed also implies a reaffirmation of previous decisions. In a decision-making process which is reversible, this reaffirmation might be made explicit to a greater or lesser extent. That is, a decision to proceed in a reversible process also involves in effect a decision not to reverse one or more previous steps. For example, a regulatory licensing decision typically involves a review of compliance with the conditions of the previous licence, and only after it is concluded that the previous conditions have been satisfied will a decision be taken on moving forward with the next steps. It has also been pointed out [Ref. 8; Ref. 25] that for the licensing decision at this stage to be meaningful, there must be at least a possibility that the decision will not be to go forward, but rather to step back and correct shortcomings encountered during the previous phase. Thus a decision not to reverse, whether taken implicitly or explicitly, has the effect of reaffirming previous decisions, and the recording of these decisions and reaffirmations at each step serves to legitimize and facilitate subsequent decisions, including the final decision on closure if and when that decision point is reached.

4.3 Decision-Making for Retrieval

Decision making on retrieval would likely be a complex process if these containers are already in sealed vaults or galleries. The example of the Asse site in Germany [Ref. 26] shows that a variety of criteria would need to be considered, relating to topics such as operational safety, environmental consequences, long-term safety, feasibility, cost, time requirements, the requirement for new interim storage and management facilities and possibly for a new repository for wastes generated during retrieval and processing of recovered materials, and transportation of waste materials. The difficulty would increase with the number of containers to be retrieved and if they were already in sealed vaults or galleries. It is likely that some form of weighting of criteria would be needed, and this weighting is likely to depend upon standards and attitudes to safety prevalent at the time of retrieval, which of course cannot be predicted at the time of emplacement of the materials. Experience also suggests that the costs of retrieval are likely to be comparable to, or even to exceed, the costs of disposal.

After closure, it is generally agreed that retrieval would be a new nuclear operation requiring a new licence. One question that may need to be resolved in some countries is ownership of the material after closure. A related issue is the possible distinction between physical closure (sealing of the last access shaft) and regulatory closure, which may be some time later in order to accommodate a post-closure surveillance period during which the operator may continue to be responsible. If the time period foreseen for such a surveillance period is very long, it may be necessary to have some method to transfer responsibility to the state, since the organization originally responsible for the production of the waste may not continue to exist, especially beyond the end of nuclear energy production in a country. Even if retrievability following closure were a national requirement or policy, retrieval will not be undertaken lightly.

4.4 Communicating on R&R

In some countries, social pressures for reversibility have been more directed towards avoiding irreversible steps rather than of specifically requiring ease of reversibility. In addition to providing access to resources and to attempt, to the extent feasible, to confirm or demonstrate repository performance, it appears that the strongest motivations for such social pressures may include unfamiliarity with (or lack of confidence in the maturity of) the technology and discomfort with the concept of purely passive safety without any means of control, as well as a desire to avoid making decisions today that might preclude different actions in the future. It is also possible that part of the motivation for demands for reversibility may be simply to recognize the perceived need for ongoing monitoring and control even after closure. On the other hand, stakeholders and the general public are more and more interested in having open options allowing for reversal, retrieval and recovery, as well as research that demonstrates that, although there is a cost, retrieval or recovery will still be feasible if it should be desired.

Communication on disposal issues is difficult because of the great disparity between geological time scales and human or social time scales and because of the uncertainty that must be communicated when describing potential impacts that may only occur in the far future. Also, there is a tendency among many non-technical stakeholders to look for absolute yes/no answers and to have difficulty understanding statements about consequences that involve low likelihoods of occurrence. This is a topic that will no doubt undergo development in most countries.

The R-scale

One of the key issues for local stakeholders considering hosting a geological disposal facility for radioactive waste is ease of waste retrieval from a repository. A scale has been developed to illustrate qualitatively the degree and type of effort that is needed to retrieve the waste before and after its emplacement in a repository, i.e. gradations in retrievability during the repository life cycle. The stages in the scale are described in Table 1, which also shows the correlation between the effort needed for retrieving the waste and the corresponding degree of passive safety of the repository. These stages may be of long or short duration, and the decisions to move from one stage to the next may be more or less formal and involve more or less public input, depending on the individual programme. 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. The scale is reported graphically in Figure 3.

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

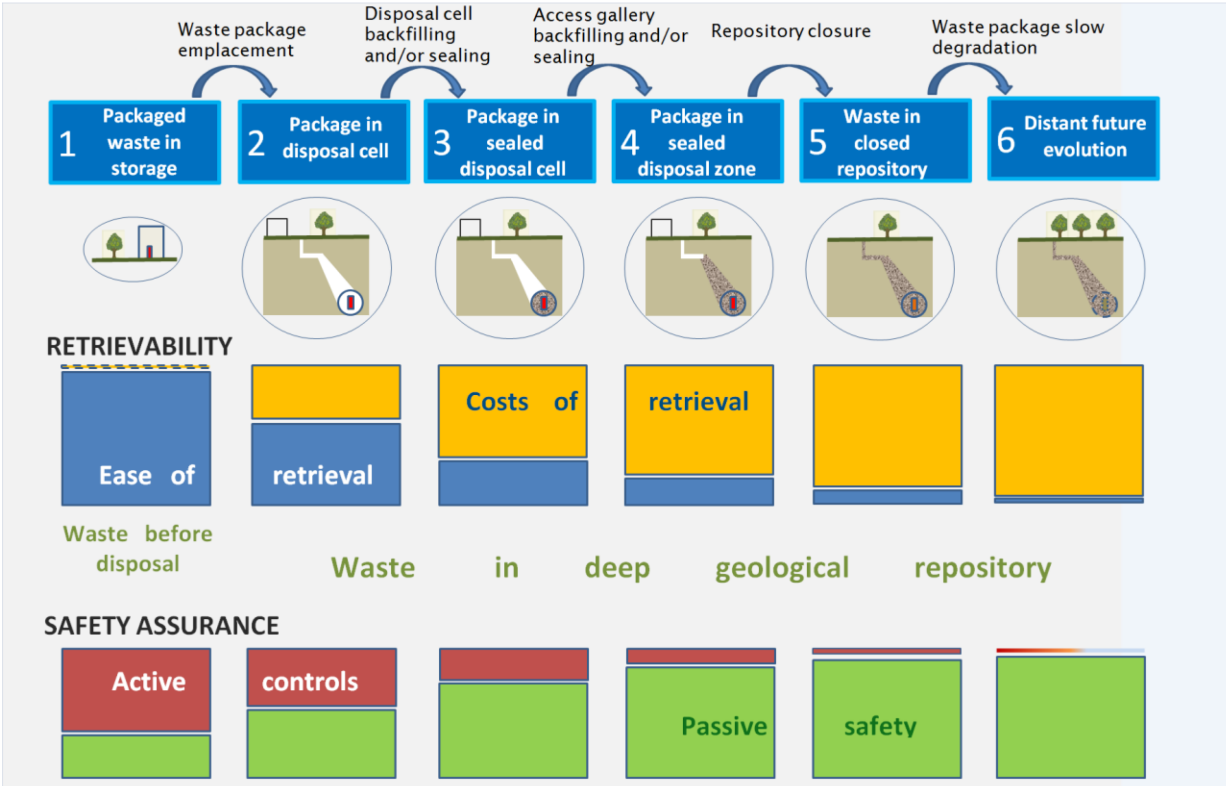
Stage and Location of the Waste		Ease of Retrieval	Specific Elements of Passive Safety	Specific Elements of Active Control
1	**Waste Package in storage**	Waste package retrievable by design	Waste form and its storage container	Active management of storage facility including security controlled area
2	**Waste Package 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 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 in sealed disposal zone**	Waste package retrievable after re-excavation of galleries	As in previous stage, plus backfill/sealing of cells and their access	Monitoring of disposal cells potentially possible. Security controlled area Detailed records and institutional controls for a specified period, including international safeguards.
5	**Waste Package 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**	Package degrading with time. Waste ultimately only recoverable 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.

With reference to Table 1, several stages can be identified in the waste lifecycle:

Stage 0 represents as-produced unconditioned waste. Stage 1 is waste conditioned, packaged and kept in an interim store. Stage 2 is the same conditioned waste moved from its interim store to an underground disposal facility a few hundred metres deep. The cell in which it is emplaced needs active monitoring. In Stage 3, passive components enclosing the waste emplacement cell are put in place: backfill (against rock disruption) and/or sealing (against water circulation). The access galleries to the cell still need active monitoring and maintenance, e.g. ventilation. These galleries are backfilled and/or sealed in Stage 4. This latter stage may coincide with the closure of the whole disposal zone in which the gallery is located or indeed of the whole disposal facility. In Stage 4 monitoring or maintenance of the disposal zone (or the whole underground facility) is no longer necessary, but the facility may still be monitored remotely. Stage 5 is the longest running one. Although the integrity of the waste packages cannot be guaranteed, the waste is still confined within the facility. By this time, the short-lived radionuclides have almost completely decayed, the overall radioactivity will also have decreased substantially, but the waste would still pose danger if people were directly exposed to it. Safety does not depend on maintenance or monitoring. However, measures intended to ensure continued memory of the site may continue.

FIGURE 3: Graphical Description of the R-Scale



A draft leaflet describing this R-scale has been used and tested at meetings with stakeholders in France and Scotland, and in consultation documents issued by the Scottish Government [Ref. 43]. This leaflet was also referred to in the Swedish National Council's 2010 report [Ref. 35]. It is hoped that the scale will prove useful for describing the evolution of retrievability during repository development in other national programmes as well.

5. INTERNATIONAL STATUS AND RELEVANT OBSERVATIONS WITHIN THE R&R PROJECT WORKING GROUP

The R&R project has performed a detailed compilation of country-by-country information which is available at [Ref. 31]. The compilation shows that while there is considerable agreement on many of the principles underlying reversibility, retrievability and recoverability, as described in the previous section, there is less degree of unanimity on whether and, if so, how these principles might be put into practice in disposal programmes. Decisions on whether or not to include provisions for retrievability or recoverability in a repository design must weigh the potential advantages against the possible disadvantages. These decisions can only be made in the context of a specific repository programme, and not for all repositories in general.

5. 1 Status of National Requirements

A brief summary of the status of reversibility and retrievability requirements in NEA member countries is found in the Text Box hereafter.

In some countries, notably France, Switzerland and the USA, retrievability during the operational life of the repository is required by law. In some others (e.g. Japan), it has not been required by law so far, but national policy calls for it during the operational phase. In Sweden, Finland and Canada, retrievability is not explicitly required either by law or by the government, but it is built into the design by the implementer nonetheless and would apply during both the operational and the post-operational phases. In most other countries, even though reversibility, retrievability and recoverability are not current issues in the national debate, they are recognised as potentially important issues by the institutional players.

National Reversibility and Retrievability Requirements
(based on responses to the RWMC R&R questionnaire, summer 2008 [Ref. 29])

Austria: N/A

Belgium: No statutory requirement for retrievability. Current policy is to avoid taking actions that would rule out retrieval, but not to require retrievability. Retrievability provisions must not be adverse to long-term safety.

Canada: No statutory requirement. However, retrievability of used nuclear fuel is a fundamental feature of the approved Adaptive Phased Management approach.

Czech Republic: No statutory requirement for retrievability. The reversibility concept is implicitly included into the stepwise DGR development approach, during which at each decision making stage several options for follow up stages will be discussed.

Finland: Retrievability of canisters is a statutory requirement. It is considered that the KBS-3 design concept meets the requirement without further special measures.

France: Reversibility is required by law during at least the first 100 years. Detailed requirements for implementing reversibility are to be developed.

Germany: Reversibility is not considered for geologic disposal in Germany. It is intended to implement safety requirements on waste containers which contribute to retrievability. The concept of retrievability itself is not an element to be licensed.

Hungary: Retrievability is required for pre-closure stages only.

Japan: Retrievability is not a requirement, but safety standards under development are likely to impose retrievability pre-closure.

Korea: No requirements for retrievability established. At this moment and according to the current design it is considered that reversibility can be possible during the emplacement of the disposal canister in the deposition hole only before backfilling of the disposal tunnel.

Spain: Statutory requirements exist for the retrievability of LLW

Sweden: There is no statutory requirement for retrievability. Retrievability provisions if adopted must not compromise safety.

Switzerland: Retrievability is prescribed by the Swiss legislation. Waste retrieval should be possible “without great effort” until repository closure. The latter is to be preceded by an extended monitoring period.

UK, excluding Scotland - Decision can be made at a later date in discussion with the independent regulators and local communities. The planning, design and construction can be carried out in such a way that the option of retrievability is not excluded.

Scotland - No plan for a deep geological repository. Higher activity wastes arising in Scotland are required to be managed in facilities which are near surface, near site so that the waste is monitorable and retrievable.

USA: Retrievability is required pre-closure for Yucca Mountain. This legislation also provides that DOE specify the appropriate period of retrievability, subject to NRC approval, as part of the construction authorization process. The WIPP regulations by the EPA require retrievability for some period of time after closure.

There are, across the more advanced national programmes, technical differences in how a balance is reached between freedom of choice and long- and short-term safety. For instance, in some programmes individual galleries are to be backfilled as soon as emplacement is complete; in other programmes all galleries are to be kept open as long as it is safe to do so. These differences will have consequences for retrievability and recoverability. In the same vein, the design and extent of monitoring before closure also differs amongst programmes.

Many of the observed differences are rooted in the different historical developments of programmes in different countries. This has led to different issues having been prominent at different stages in the process, which in turn results in differences in requirements and the way those requirements are expressed. Different social, cultural and legal environments in different countries also lead to different attitudes towards reversibility, retrievability and recoverability.

5.2 Main Observations and Converging Views within the R&R Project Working Group

Dspite the variability of national positions, a number of important points of agreement have emerged within the working group of the R&R Project.

There is general agreement that, on long timescales, when today's societal institutions can no longer be counted on, hazardous waste must be disposed of in a way that protects the health and safety of future generations without requiring continued care and monitoring. There is also general agreement that waste should be emplaced in a final repository only when there has been a policy decision ensuring that the material to be disposed of is actually waste and not a resource to be used in the foreseeable future. If there is a clear intention to retrieve the material as a resource at any time, storage would be the appropriate option. This is a national policy question to be decided before proceeding with disposal.

There is also agreement that safety regulations for the protection of man and the environment must be complied with before and during the process of repository development. The existence of retrievability or recoverability provisions as a feature of a repository programme must not be used as an excuse for an immature disposal project to move forward.

The requirement to meet safety regulations for the protection of man and the environment without the necessity for active control must be met in any country that is a signatory to the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management. This includes all countries with major nuclear power programmes.

It is also agreed that stakeholders must be appropriately consulted during all phases of the programme, starting before approval is granted to begin construction of the repository. Public consultation is also required under international conventions, notably the Aarhus convention [Ref. 44], and is an essential part of a democratic decision-making process.

The ability or potential for re-accessing and re-capturing the waste during operations may be part of the operational safety concept of the repository. Retrievability provisions may provide, for instance, additional flexibility for the management of an unexpected situation during operation. The action of retrieving waste for operational reasons is not an action that necessarily puts in doubt the safety of a facility, but in fact may increase it. Retrieving waste during the operational phase could be carried out in order to perform maintenance or repair on containers, or it could be intended to better characterize the waste or to recondition it, and to re-emplace it in the repository.

Although it is not part of the long-term safety concept, retrievability may thus contribute nevertheless to the assurance of long-term safety by helping to ensure that the reference design is correctly implemented and that improvements can be effected during the operational phase.

Retrievability also helps provide the technical basis for eventual retrieval of the waste, if needed.

During discussions it was noted that the social pressures for retrievability may in a number of cases be more in the direction of avoiding irreversible steps rather than of specifically requiring ease of reversibility. In addition to accessing resources and the ability to continue to directly monitor conditions in the repository, it appears that the motivations for such social pressures may include unfamiliarity with (or perceived lack of maturity of) the disposal technology and discomfort with the concept of purely passive safety without any means of oversight or active control, as well as a desire to avoid making decisions today that might preclude different actions in the future. A number of these drivers may decrease over time as the level of familiarity and trust in a programme increases over time, and an extended period of control may also increase familiarity and willingness to accept passive/intrinsic safety. In this context, the inclusion of retrievability provisions may be seen as mitigating a risk, namely the risk that a repository project will not go ahead and the wastes will be left in a state that is not assured to be tenable in the long term.

Attitudes may also change between different localities and situations. In Sweden, for example, it has been observed that different interest groups (non-governmental organisations) have opposing views on the desirability of retrievability. Some feel that retrieval should be made as easy as possible in order to facilitate future freedom of choice, while others consider that retrieval should be made as difficult as possible in the interests of safety, i.e. in order to minimise the likelihood that future generations will come into contact with the waste.

In any event, if there is an issue of retrievability provision versus safety, it is generally agreed that safety must come first. In the very long term, attempting to facilitate retrievability by keeping a repository open longer than otherwise necessary could become detrimental to safety (e.g. a facility designed to be safe when properly sealed and closed may not be as safe if it is abandoned without sealing and closure, and keeping a repository open for a long period of time may increase the risk of this occurring).

6. CONCLUSIONS

Note: *At this stage in the project, these conclusions are based on the work of the R&R Working Group. Inasmuch as the membership of that group has been largely limited to members of the waste management community, these conclusions may not reflect adequately the views of other constituencies. The discussions at the Reims conference in December 2010 will help remedy this.*

- The most widely adopted policy for the definitive management of high-activity radioactive waste involves its emplacement in deep geological repositories whose safety should not depend on the active presence of man. Repositories are thus designed to be robust to a large spectrum of events and to prevent the release of their radioactive contents in amounts that would be harmful to man and the biosphere. In particular, such final repositories must be designed and licensed with the express intention not to retrieve the waste.
- The policy of concentrating and confining radioactive waste in a final repository, as opposed to a policy of dilution and dispersion, creates *de facto* a situation where the waste could be re-accessed over very long time scales. Geological disposal, as currently envisioned in all national programmes, is in principle always reversible or, in other words, never completely irreversible. Waste recovery would be possible over timescales that extend over millennia, albeit likely at great effort and expense. Some of the critics indeed object to the fact that geological disposal, as currently envisioned, is never irreversible.
- The extent to which re-accessing and retrieval of the waste should be facilitated in designing a repository, both before and after closure, is an issue of continued interest in NEA member countries.
- Two complementary principles may be invoked: an internationally-agreed principle of not placing undue burden on future generations, which is mentioned in international safety fundamentals and can be interpreted as requiring the removal of all future responsibilities for safe-keeping of the waste as soon as possible, and a guiding principle of not depriving future generations unnecessarily of the possibility to exercise choice, which is found variously in the literature - including national positions - and can be interpreted as involving a more progressive release of controls. Reversibility and retrievability facilitate such a progressive release of controls.
- Because repository implementation and development will take place over many decades, many programmes recognize the necessity of remaining flexible and adaptable, e.g., in order to incorporate new knowledge about site conditions or the possible evolution of the disposal system. Reversibility and retrievability can be argued to be helpful to that effect.
- As used in this document, in waste disposal, **Reversibility** describes the ability *in principle* of reversing decisions taken during the progressive implementation of a disposal system. It requires managing the implementation process and technologies in such a way as to maintain as much flexibility as possible so that, if needed, reversal of one or more previous decision(s) in repository planning or development may be achievable without unnecessary effort. **Reversal** is the action of undoing a previous decision. **Retrievability** is the ability *in principle* to retrieve whole waste packages once they have been emplaced. Retrievability is the final element of a studied and fully-applied reversibility strategy. **Retrieval** is the actual action of recapture of the waste packages, whereas retrievability is the potential for retrieval. **Recoverability** is the ability *in principle* to recover the waste materials regardless of the presence or otherwise of packaging materials.
- Reversibility affects the entire process of repository development from its inception to final closure, i.e., until the absence of any remaining need to retrieve the waste is confirmed, once again, by the final approval to close all access to the repository. A reversible approach in repository development should not be taken to imply a lack of confidence in the ultimate safety of disposal. It

should be regarded rather as a way to make optimum use of available options and design alternatives during the evolution of the programme.

- To the extent that retrievability is about retrieving whole waste packages, there exist means to enhance retrievability, e.g., by implementing more durable containers and waste forms. Other approaches may rely on longer times before emplacing backfill materials or sealing galleries and the whole repository. There is, however, a delicate balance to consider, whether this may or may not jeopardise safety, both for present and for future situations. Cost is also a factor, as more durable containers may be more expensive, and the longer a facility is kept open, the higher the costs will be.
- On the other hand, an extended ability to retrieve the waste can be seen as providing further assurance of safety, in that, during the operational phase, intervention is possible to correct problems, and in the post-operational phase it is safer to get to the waste if the need should arise or if it were decided to re-access the waste for reasons other than safety.
- In practice, during the emplacement phase, unless there are serious problems with the repository concept or its implementation, retrievals are likely to be rare events and would likely only be carried out for a small number of containers (if any) and only for operational reasons.
- The need for retrieval following emplacement would be expected to be even less, as safety cases for waste disposal must be prepared and accepted prior to emplacement showing to the satisfaction of many reviewers, and principally the regulators, that the implemented designs are robust to a very wide spectrum of processes and events so that post-closure safety does not rely on human intervention.
- It is in nobody's interest to use retrievability as an excuse to implement an immature programme. It must be understood that any decision to retrieve wastes after even partial closure would be a major decision. Retrieval or recovery would be costly and would pose safety hazards. If future standards are similar to today's, as it must be assumed in today's decision-making, then retrieval will be a regulated activity. It will require facilities to accept and manage the retrieved or recovered wastes safely.
- The social pressures for reversibility and retrievability may be more in the direction of avoiding irreversible steps rather than of specifically requiring ease of retrieval. In addition to the ability to access materials that may become valuable at a future time and the ability to continue to directly monitor conditions in the repository, it appears that the motivations for such social pressures may include unfamiliarity with (or lack of maturity of) the disposal technology and discomfort with the concept of purely passive safety without any means of oversight or active control, as well as a desire to avoid making decisions today that might preclude different actions in the future. A number of these drivers may decrease over time as the level of familiarity and trust in a programme increases over time. An extended period of control may also increase familiarity and willingness to accept passive/intrinsic safety. In this context, the inclusion of reversibility and retrievability provisions may be seen as mitigating a risk, namely the risk that a repository project will not go ahead and that the wastes will be left in a state that may be untenable in the long term.
- The position of many national programmes is that, from a technical point of view, flexibility in implementing the repositories is a recognised management approach. Retrievability is subsidiary to reversibility and flexibility. It is an option that could be exercised if the need arose.
- In the national programmes that include retrievability as a declared feature in implementing a final repository, the goal is not to make future retrieval easy or cost-free; it is simply to ensure that it is feasible, assuming a future society that is both willing and capable to carry it out.
- No national programme requires retrievability as a safety feature of waste disposal either pre- or post-closure. A final repository has to be declared safe without consideration of retrievability. Those programmes that require retrievability mention three main reasons (a) having an attitude of humility towards the future; (b) providing extra assurance of safety; (c) heeding the desires of the public not to be seen as taking an "irreversible" decision from the start. Accordingly, the

regulations for these programmes do not require that retrieval be demonstrated in practice. They require only that retrieval could be exercised in principle. There is, however, a trend, independent of regulation, to confirm experimentally that retrieval of disposed-of containers will be possible. Experiments have been devised and run successfully. R&D is being performed in several countries.
- Although the long-term safety case must be able to stand on its own without them, specific post-operational institutional oversight provisions, such as monitoring and memory keeping, may nevertheless be decided upon. If so, these may further contribute to decision-making relative to retrieval post-operation, and to the freedom of choice provided to future generations.
- During the operational phase, parts of the repository may be backfilled and sealed while other parts are still open. For those parts of the repository that remain open, the operational safety case may rely upon retrievability, for example in order to permit correction of problems arising during implementation. However, the safety case for closed portions of the repository, like the safety case for the post-operational phase, should stand on its own, i.e. without the need to rely upon retrievability to ensure safety.
- One important reason why there is difficulty in discussing reversibility and retrievability nationally or internationally is that relevant basic terms and concepts, such as "disposal", are understood differently by different national stakeholders and/or used differently in the different countries.
- For clarity, it is important from the start to designate a repository as a final facility and its contents as waste. In cases where retrievability is not chosen as a matter of basic policy and in the absence of a clear designation of finality, retrievability may still be considered necessary to the extent that a repository, *before closure*, may be seen as a hybrid between a storage facility and a final disposal facility.

Because they touch on freedom of choice and its relationship to safety, the concepts of R&R link societal and technical considerations, and tend to be central in the debate on "disposal" when, besides the technical audiences, the public and society and large are involved; hence the continued interest in these topics.

Reversibility and retrievability respond to the guiding principle of preserving options for future generations. "How should options be preserved?" and "for how long a time is it considered reasonable or desirable to preserve these options?" The answers to these questions depend upon technical, political and social factors, and are therefore variable from country to country. Some of the tradeoffs that may need to be considered could include:

- Improved acceptance, decreased risk of project failure due to lack of acceptance vs. delays, costs, and the risk of perception of inadequacy of disposal as a result of invoking retrievability.
- Ability to correct operational faults vs. potential safety impacts and increased cost of postponing closure or backfilling.
- Ability to change strategies as appropriate vs. an increased need to take an active role in continued control.
- Increased cost of more robust containers and underground structures vs. safety benefits as well as retrievability.
- Increased cost of R&D to support retrievability, risk of increased perception of problems vs. benefits of improved knowledge.
- Increased difficulty of safeguards vs. benefits of retrievability.
- Ability to access materials that may become valuable at a future time vs. the need to ensure safety without imposing a burden of control.

In addition to depending on such technological factors as the nature of the waste (spent fuel containing known energy resources vs. HLW) and the geological surroundings (which affect both the likelihood and consequences of radioactive materials reaching the environment as well as the ease of retrieval), there are also societal factors that have a major influence (e.g. societal attitudes towards freedom of choice vs. assurance of safety, and the degree of optimism with respect to future technological developments). *It is reasonable to expect that the points of balance among these competing factors will differ from one country to another and even from one time to another in a given country*.

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