5.5.3 Retrievability, Domain Insight

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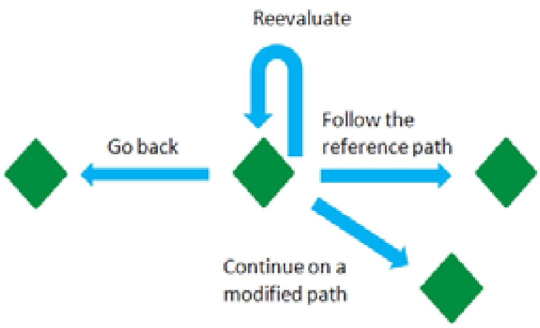
Overview

The concepts of reversibility and retrievability initially respond to a political demand for the disposal of radioactive waste in a geological environment. However, they can be extended to all forms of disposal, including land disposal facilities. The term deep geological repository (DGR) will be used in this text since it is the most current application.

Retrievability is commonly defined as the capacity to physically retrieve (remove, recover) nuclear waste (generally conditioned in nuclear waste packages, NWP) from its underground environment (DGR) where it has been emplaced. Retrieval operations are activities likely to be implemented following a decision-making process, which may vary from one member state to the other, and which will have opted at the end for removal. Such a decision of retrieval implies specific operational safety measures, which are commensurate with the design, construction and operation features integrated in the DGR to facilitate and enable the potential recovery of the waste packages. A thorough evaluation of the DGR environmental conditions (and of the physical phenomena likely to occur) prevailing at time of removal is also necessary before starting packages recovery, since operational safety is conditioned by the degree of knowledge collected prior to effective retrieval activities start-up.

Retrievability is one aspect of a wider concept called **reversibility,** an acceptation which not only encompasses **retrievability** (i.e. partial or complete removal of waste packages), but also **flexibility** (the capacity to operate, postpone, stop or pursue staged disposal operations), **modification** of DGR design set-up/construction features/operational modes (e.g. following optimisation of process or disposal system re-evaluation), **change** of the disposed NWP inventory (e.g. nature of waste) and/or **evolution** of the waste packages (e.g., reconditioning), hence change of their waste acceptance criteria (WAC).



Potential outcomes of reversibility (NEA 2011)

Retrievability capacity is a design/construction/operation issue integrated or not as a pre-requisite in the nuclear regulations governing the different national DGR projects, since member states concerns regarding this matter, at present, differ from one country to the other. However, some waste management organisations (WMOs) in charge of implementing a DGR solution are considering technical provisions to anticipate the possible change of stakeholders' position on retrievability and have consequently planned retrieval tests (either at stage of early design or at time of disposal activities) to check (demonstrate and share confidence in) their technical capacity to effectively reverse/modify a disposal configuration/situation which would not be deemed relevant or acceptable anymore.

Note: Retrievability and reversibility concepts were developed and are mainly debated for disposal of NWP in DGR but such concepts can be applied to address other issues such as deep disposal of chemicals (e.g. Stocamine case story - www.mdpa-stocamine.org).

Keywords

Monitoring, Operational Safety, Member State, Nuclear Authority, Nuclear Waste Package, Waste Management Organisation, Phenomenology, Regulator, Retrievability, Reversibility, Stakeholder, Waste Acceptance Criteria.

Key Acronyms

DGR – Deep Geological Repository

EBS – Engineered Barrier System

NEA – Nuclear Energy Agency

NWP – Nuclear Waste Package

WMO – Waste Management Organisation

WAC – Waste Acceptance Criteria

1. Typical overall goals and activities in the domain of Retrievability

This section provides the overall goal for retrievability, extracted from the EURAD Roadmap goals breakdown structure (GBS). This is supplemented by typical activities, according to the phase of implementation, needed to achieve the domain goal. Activities are generic and are common to most geological disposal programmes.

Domain Goal	
5.5.3 Establish technical feasibility of waste reversal after emplacement and potential waste retrieval after operation and if required, demonstrate in full-scale representative conditions before the start of operations (Retrievability).	
Domain Activities	
Phase 1: Programme Initiation	When elaborating their national nuclear waste management programmes, member states (governments, regulators, stakeholders, etc.) must specify (by law or regulation) to the concerned WMOs their position regarding retrievability capacity and the need for integrating this requirement in the design, construction, operation and closure phases of the DGR facility. In the early phases of a disposal programme initiation, it is essential to assess the waste gross inventory, the overall operations schedule and the size of the facility that is anticipated. The decision-making process with regards to retrievability must similarly be dealt with by positioning in the baseline of the disposal project development and closure scheme different decision milestones, throughout its lifetime.
Phase 2: DGR Site Identification	
Phase 3: DGR Site Characterisation and identification of future possible perturbations	Characterise or confirm the hydrogeological, chemical, geomechanical, thermal, geomicrobiological, gaseous and radiation-induced perturbations which may be caused by the underground facility construction, operations (including NWP emplacement) or closure and their impacts on the deep disposal system evolution (i.e. short-term phenomenology) in view of assessing the environmental situation and related operational risks prior to implement removal activities.
Phase 4: DGR Construction	Design and build a facility that fulfils safety and security requirements and that can be practically constructed, operated and closed (disposal facility design and optimisation), but which also integrates the necessary provisions for waste removal (if such retrievability criteria are required) with the same level of safety and security. Demonstrate and verify that facility components and engineered barriers can be practically manufactured, constructed, and installed in accordance with detailed design requirements and specifications, but also make sure (demonstrate) that deconstruction of facility components and waste package recovery process are possible and safe (verification tests).

Phase 5: DGR Operation and Closure	Identify retrievability operational hazards or risks and implement measures to eliminate these or provide a means of preventing the outcome, protecting those affected and mitigating the consequences (operational safety). Collect complete data linked to phenomenology (environmental situation of DGR) to identify and assess the risks. Maintain a complete memory system (not only of inventory, but also of construction and operation phases) to master and preserve general knowledge and know-how with time.

2. Contribution to generic safety functions and implementation goals

2.1 Contribution of Retrievability to achieving operational safety while preserving long-term safety of the disposal system

2.1.1 Primary goal - relied upon for: Practicability

Retrievability **practicability** must be assured throughout the DGR lifetime, i.e. from its construction until its final closure is decided and implemented. It means that operational safety linked to NWP removal is effectively preserved at various levels/phases of disposal life (e.g., capacity to safely deconstruct an engineered barrier system (EBS) closing a disposal zone in the DGR) and that all the human skills and knowledge as well as the technical and industrial means necessary to implement such removal activities are easily made available or maintained at hand.

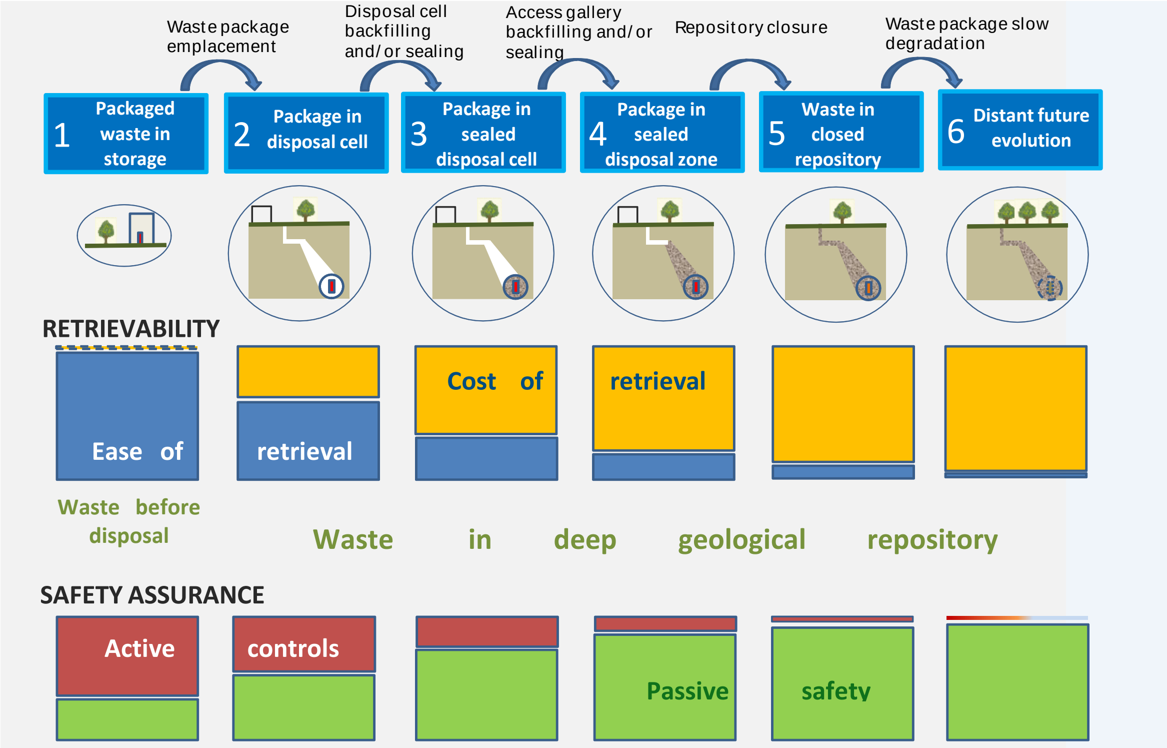
Retrievability **practicability** features must also remain compatible with long-term safety goals and requirements, i.e. the technical provisions taken to decide/facilitate/preserve removal capacity must not impede the DGR overall containment performance (e.g. positioning, wiring, and powering of monitoring sensors must not constitute a potential radionuclide by-pass inside an EBS, a situation detrimental to passive safety, and maintaining handling equipment in place inside a vault must not generate a hazard due to corrosion induced explosive gas).

From a pragmatic point of view, the retrievability rationale is twofold and summarised in the International Retrievability Scale (presented at NEA “R&R” Conference and Dialogue in Reims, December 2010) here below:

- NWP retrieval practicability (ease) is progressively diminishing (cost and duration of removal are increasing) with time since direct access to the NWP is impeded by the progressive backfilling and closure of disposal zones, inducing the need for reopening the access drifts and disposal vaults and putting back into active mode various functions (power, ventilation, machinery, etc.).
- Passive safety, on the contrary, is more effective as DGR backfill and closure operations are implemented and generalised to the entire facility (disposal vaults, chambers or cells, drifts, shafts, and access ramps).

At all phases of the progressive DGR backfill and closure (e.g. closure of a disposal vault, closure of a complete disposal panel), a decision-making process can be conducted to pursue, postpone, stop disposal operations, and decide to retrieve or not the NWP. The retrieval decision outcomes will lead to a new operation plan, the complexity, cost and duration of which are commensurate with the extent and age of the disposal zone concerned (and its expected environmental evolution).

Such retrieval activities are likely to be preliminarily approved following a specific licensing procedure under the authority of the nuclear regulator.



International DGR Retrievability Scale (NEA 2010-2011)

2.1.2 Secondary goal – acknowledged but not relied upon for: **Radiological protection**

The key radiological protection critical issues for safe retrievability operations are summarised hereafter:

- containment to prevent spreading (dispersion) of radioactive material: potential NWP degradation with time must be assessed,
- reduce human exposure thanks to the use of remote operated equipment (including robots and drones),
- need for HEPA filters on nuclear ventilation airducts, adequate protection suits for workers, vinyl and tarps for equipment, if any NWP leakage or NWP surface contamination is suspected or detected,
- adequate ventilation to prevent/mitigate potential critical concentration of explosive gases generated by NWP or by steel structures,
- heat management (thanks to ventilation) to dissipate/mitigate waste decay heat in the DGR drifts and disposal vaults and at contact with shielding equipment,
- shielding to prevent harmful radiation levels.

These radiological protection issues are common to both NWP emplacement and retrieval operations. They are however more critical at time of retrieval, since the evaluation of the disposal system relies in part upon a proper assessment of the local environmental situation prevailing. A specific risk analysis must then be conducted prior to initialise the retrieval activities, such analysis being fed by phenomenology data and the return of experience gained (the preserved know-how) during initial disposal operations. Additional in-situ characterisation (to detect potential contamination or accumulation of explosive gas) inside disposal vaults/cells/chambers, if possible, must be conducted to supplement knowledge before active retrieval start-up.

3. International examples of Retrievability

Some examples of retrievability/reversibility issues (or case stories) are listed below to provide insight from a few countries (different WMOs) dealing with disposal of NWP in a DGR (be it for disposal of high-level waste or for that of low-level and intermediate-level long-lived waste).

These examples have been selected to illustrate the different approaches from one country to the other (from one DGR to the other) from a practical point of view, some opting for retrievability, others for reversibility.

WIPP (US DOE - USA): The Waste Isolation Pilot Plant was constructed for disposal, in a New Mexico salt formation, at some 660m of depth, of defence-generated transuranic (TRU) waste from DOE. The facility started disposal operations in 1999 and experienced an underground nuclear related incident in 2014: a waste package (a contact-handled drum) opened, and a subsequent airborne release of radiological material occurred, exposing some workers to small doses of radiation. This nuclear event led to a temporary stoppage of operations and to a thorough re-evaluation of the disposal facility set-up and of its operational modes prior to resume disposal activities in 2017, after clean-up of contaminated openings (drifts and shaft). An upgrade of the facility architecture was launched (e.g., sinking- as of 2017- of a new shaft dedicated to ventilation, beef-up of the surface HEPA filters system capacity, etc.). Additional work was also carried-out at the distant DOE site where the type of NWP in question is manufactured (reconditioning, new packing material, additional control procedures, etc.) to prevent a similar package-opening problem. In that instance, disposed packages were not recovered from underground. Reversibility (evaluation and evolution) prevailed on retrievability (removal), since the modifications of the facility architecture and those of the ventilation system, as well as the evolutions of the operational modes (new packing of waste, hence new WAC) were deemed relevant and sufficient to resume safe and secure disposal operations.

Asse Mine (BGE - Germany): The Asse Mine, located in Lower Saxony, is a former salt mine used as a deep geological repository for low- and intermediate-level radioactive waste, emplaced inside chambers at various depths between 500 m and 750 m. In April 2017, operator’s responsibility for Asse was transferred to BGE. Disposal activities were conducted in different campaigns between 1967 and 2004. The instability of the mine (subsidence linked to local collapse of the overlying rock) and the subsequent local water ingress observed led to controversies (fears of brine contamination and later of potential biosphere pollution). The initial DGR operation scheme planned a permanent backfill and closure of the facility, without the intention of potential waste removal, which was deemed “not relevant” by many. Nevertheless, at the end of long and complex debates, the recovery decision was acted by the stakeholders (government, NGOs and public). Many technical and operational issues are at stake with regards to the facility as is, since a significant number of challenges (risks of different nature) linked to mine stability, and disposal conditions (e.g., some drums are physically damaged and have lost their containment function, nuclear waste inventory is complex, explosive gas occurrence is not unlikely, etc.) must be dealt with. Dedicated new installations are considered for the retrieval of the NWP (e.g., a surface interim storage of the recovered waste, a dedicated shaft for the transport of the removed packages, a reconditioning installation to provide containment to the damaged packages, etc.). Removal operations are planned to start after 2030 and are estimated to last for decades (cost and duration assessment is under way). In that instance, total and effective retrievability prevails on reversibility but remains to be demonstrated.

Onkalo Spent Nuclear Fuel Repository (POSIVA – Finland): The deep geological repository for the final disposal of spent nuclear fuel (SF), now under construction and operated by POSIVA, is located at 520 m depth, in a hard rock (crystalline) formation, on the west coast of Finland. It is the world’s first long-term disposal facility for SF (high-level radioactive waste) and is expected to be operational in the late 2020s and for a period of about 100 years before the repository is closed. Finland's Nuclear Safety Authority (STUK) is currently reviewing POSIVA's operating licence application. Retrievability of SF packages (commonly called canisters) is not an explicit policy request or regulatory requirement and as such is not a part of the licence application. However, POSIVA carried out in 2019 the Full-Scale In-Situ

System Test (FISST): two test (dummy) canisters were installed in vertical deposition holes located in the Onkalo site demonstration area, in a tunnel about 50 m long. The tunnel was later filled with bentonite and closed with a steel-reinforced concrete plug in the same way as in the actual final disposal. The test canisters were equipped with heating elements simulating the heat power generated by SF. Temperature and pressure evolutions of the canisters, deposition holes and surrounding bedrock as well as behaviour of tunnel backfill material are monitored thanks to many sensors. FISST outcomes provide further information on whether the engineered barriers are operating according to the initial assumptions (short-term phenomenology). FISST primarily demonstrates the technical feasibility of final disposal (i.e. the capacity of specific mechanical devices to remotely emplace canisters and bentonite blocks and to reverse the process by retrieving the canisters and the bentonite blocks from the deposition holes) but it also provides knowledge on the environmental impacts of the initial disposal phase, a short period in view of the final disposal time. Retrievability capacity is addressed by FISST since the phenomenological situation is taken in consideration and mechanical processes show their capacity to remove canisters and bentonite bricks from the deposition holes at early stage of repository operations (Level 2 and Level 3 of NEA retrievability scale).

Forsmark Spent Fuel Repository (SKB - Sweden): The DGR for the final disposal of SF, to be constructed and operated by SKB, is planned at 500 m depth, in a hard rock (crystalline) formation at the east coast of Sweden. The Swedish DGR license application was approved by the Swedish Radiation Safety (Nuclear) Authority in 2022. SKB has developed an underground research laboratory (URL; called the Äspö HRL) in Oskarshamn since the mid-90s, also in hard rock and at 450 m depth. This HRL facility enabled SKB to test different opening excavation methods, various NWP mechanical emplacement technologies as well as EBS and backfill systems. The HRL research and development outcomes constitute the drivers for the future design, construction, and operations of the Forsmark DGR. A significant experiment is underway (2023-2024) at Äspö: the retrieval of the “prototype repository” (a full-scale experiment, which simulates conditions of relevance to the Swedish/Finnish KBS-3V disposal concept for SF). Six vertical deposition holes contain full-scale copper canisters surrounded by bentonite buffer. The system has been monitored for 20 years. SKB elaborated the planning of the retrieval of the inner section of the prototype repository including the four innermost canisters and the copper and concrete test specimens installed in the buffer and backfill. Even though the main purpose is to confirm the anticipated system components behaviour with time and to compare the collected data with the phenomenological prediction, the capacity to deconstruct EBS and mechanically retrieve canisters will be effectively demonstrated. Even if retrievability capacity is not a policy or regulatory requirement for SKB, this matter is addressed since phenomenology is dealt with, and mechanical processes are mobilised to show the capacity to remove canisters and bentonite blocks from the deposition holes after 20 years in representative repository conditions (Level 2 and Level 3 of NEA retrievability scale).

Cigéo (ANDRA – France): Cigéo is managed by ANDRA. This DGR project, whose license application is being assessed by the French Nuclear Authority (ASN), is planning the final disposal of intermediate-level waste (conditioned in cubic shaped concrete packages) and high-level waste (mainly vitrified waste, conditioned in steel canisters) in a sedimentary indurated clay formation at 550 m depth in eastern France (Bure area). In the close vicinity of the DGR site, ANDRA has been operating an URL for more than two decades and a surface technical showroom where NWP mechanical emplacement equipment is displayed. NWP retrievability capacity is a Cigéo regulatory requirement and must be enforced and demonstrated in-situ and supported by preliminary testing already carried-out at stage of licensing. The retrievability subject is dealt with in the DGR license application file (a dedicated document has been elaborated). The FSS (full scale seal) representative test was conducted in 2014-2016, inside a surface horizontal concrete lined drift mock-up, to check the capacity to industrially construct and later dismantle an EBS (i.e. emplacing/removing bentonitic buffer material and building/deconstructing the concrete plug, aka containment wall). The operational (environmental) conditions prevailing underground (mine ventilation, atmosphere control and monitoring – air filters, temperature, and humidity) were simulated. It was established (as also evidenced in the Finnish and Swedish DGR retrieval tests) that safe deconstruction of an EBS is possible, and more generally that drift reopening is not an obstacle to NWP retrieval. The full scale industrial prototypes developed for mechanical emplacement of the waste packages were also successfully tested (in surface installations) and adapted to check their ability to safely remove NWP both for the intermediate-level waste conditioned in concrete cubic containers (handled by a rail-mounted crane device traveling inside a horizontal concrete lined vault) or for the high-level waste conditioned in steel canisters (handled by a pushing robot moving inside a horizontal steel lined disposal cell). The retrieval test cases included some penalising environmental situations that can occur over time in the concrete-lined disposal vault (e.g. misalignment of cubic containers, local breakage of a guiding rail, etc.) or in the steel-lined disposal cell (e.g. generation of hydrogen with steel corrosion, build-up of rust flakes likely to jam the shielding equipment, etc.). Specific inspection robots (video camera, contamination detectors, gas chromatographs and heat sensors, etc.) were also developed and satisfactorily tested. The mechanical tests carried out for the two types of NWP (two types of disposal configurations) show that removal of nuclear packages is possible at Level 2 and Level 3 of the NEA retrievability scale.

Conclusion: The practicality of retrievability has so far been physically proven by different representative full-scale tests, at Level 2 and Level 3 of the NEA scale, but not in a real nuclear environment with real radioactive NWP. In a DGR, radioprotection issues (gas, contamination) are complex and difficult to predict precisely. The need for technical provisions and specific equipment to facilitate removal operations has been proven. Additional characterisation of the concerned disposal zones is recommended. A risk analysis prior to removal seems mandatory to feed the operational protocol and assess the pros and cons (costs and benefits) of such activities. Complex situations like the Asse Mine case (at Level 4 of the NEA scale) may lead to arbitration between full and partial retrievability. In other circumstances (like the WIPP case), reversibility (evolution) may prevail.

4. Critical background information

Key interfaces with other domains of the EURAD GBS (Goals Breakdown Structure) are listed below (with comments) as the most relevant examples of information, data or knowledge activities that may impact the appropriation of retrievability (and reversibility) issues and concepts by WMOs and that can help to address the related concerns.

GBS Domain *1.3.2 "Develop and maintain a technical and management skill base within the programme, meeting national regulatory competence requirements (Skills and Competence Management)".*

Comments: This recommendation applies to all phases of the DGR life. It becomes more critical and challenging to maintain know-how and knowledge as the DGR position in the NEA retrievability scale is passing from Level 4 to Level 5.

GBS Domain *1.3.3 "Use the knowledge, technology and experience gained internationally and co-develop RD+D where possible to improve and consolidate confidence in the scientific and technical data base, to help reduce risks to successful programme implementation and to avoid unnecessary costs (International Cooperation)".*

Comments: The retrievability background and cooperation are presently limited. If such data as decision-making process proceedings and effective return of experience/technical reports are available from another NWMO, they are to be scrutinised and shared if possible (cf. SKB's invitation to share their "Retrieval Test" programme).

GBS Domain *2.1.3 "Assess potential technologies for the implementation phase, considering cost-benefit ratio and availability (Technology Selection)".*

Comments: As much as possible, the technologies already used for emplacing the NWP should be explored, tested, and adapted to cater for potential retrieval. If successfully developed, the removal technologies available constitute readymade solutions and are a proof of concept, in support to the decision-making process. The cost-benefit ratio is elaborated after the completion of the risk analysis carried out ahead of any retrieval activities. This ratio will also support the decision-making process.

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GBS Domain *2.3.2 "Evaluate potential for improving and optimising implementation phases with new technologies, to improve costs and environmental impact while maintaining safety and accounting for potential accident scenarios (Optimisation)".*

Comments: Any potential improvement or optimisation of implementation phases should also be scrutinised to check whether such evolutions are likely to impede/diminish/improve retrievability.

GBS Domain *3.3 "Identify appropriate buffer, backfill and seal/plug materials and designs, and confirm their properties, behaviour and evolution for the selected repository concept (Buffers, backfills, plugs and seals)".*

Comments: Retrievability activities may imply deconstructing an EBS already built (and eventually monitored). Knowledge acquired on EBS construction and behaviour is a technical asset and is part of the relevant input data preceding dismantling operations.

GBS Domain *4.2.1 "Characterise or confirm the chemical, hydrogeological, geomechanical, thermal, geomicrobiological, gaseous and radiation-induced perturbations which may be caused by facility construction, operations or closure and their impacts on long-term disposal system evolution (Perturbations)".*

Comments: This recommendation also applies to the evolution of the disposal system in the short-term, during a few decades of hydraulic, thermal and mechanical transients (short-term phenomenology), because an appropriate environmental assessment of the concerned disposal zone is critical (e.g., explosive or radioactive gas generated by NWP can affect the long-term containment performance and also be a short-term hazard for retrievability operations).

GBS Domain *5.2.1 "Develop, adapt and/or buy the technology and systems required to be able to construct and then commission the facility (Pilot-scale, full-scale testing, and active commissioning)".*

Comments: This recommendation also applies to the existing technology and systems tested relevant to facilitate or implement retrievability.

GBS Domain *5.2.4 "Utilise available robotics and remote handling technology - all reliably tested beforehand - to optimise facility construction and operations (Robotics)".*

Comments: Same comments as for Domain 5.2.1.

GBS Domain *5.2.5 "As a supplement to in-situ testing (cf. 5.2.1), consider simulating facility operations by using remote technologies and models to predict the most important variables of the disposal system implementation processes (Virtual Reality/Digital Twin)".*

Comments: Same comments as for Domain 5.2.1.

GBS Domain *5.4.2 "Identify operational hazards or risks and implement measures to eliminate these or provide a means of preventing the outcome, protecting those affected and reducing the consequences (Normal operations safety)".*

Comments: Same comments as for Domain 5.2.1. A risk analysis will be fed by short-term phenomenology data (including information provided by monitoring in-situ sensors if any) and if possible improved by additional characterisation (robots, cameras, chromatographs, etc.).

GBS Domain *5.5.2 "Establish plans and methods for implementing a monitoring programme to be performed during site investigation, construction and operational phases of the repository (Monitoring with regard to onsite investigation, construction and operations)".*

Comments: Monitoring disposal vaults/chambers/cells (or some of them only if deemed representative) and data analysis are of great help, not only to check the relevance of the situation, but also to detect abnormalities and feed a risk analysis if removal of (some) NWP is decided.

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GBS Domain [*5.5.3 "Establish technical feasibility of waste reversal after emplacement and potential waste retrieval after operation and if required, demonstrate in full-scale representative conditions before the start of operations (Retrievability)"*]().

Comments: This is the essence of the current domain insight. This recommendation has been partly followed by POSIVA, SKB and ANDRA. Some pending points remains to be discussed and challenged in **Chapter 6.**

- Should retrievability tests be carried out after the start-up of disposal operations, i.e. with some real radioactive packages already emplaced in the disposal cell (Level 2 of the NEA Retrievability Scale), hence with real radioprotection concerns?

- Should retrievability demonstrations with real NWP be implemented only at early stage (a few years) of Level 3 of the retrievability scale (disposal cell/vault "recently" sealed) or also at a later stage (i.e. after a few decades)?
- Does it make sense to test effective retrievability at Level 4 (disposal zone sealed) or Level 5 (DGR entirely sealed and backfilled) of the scale?

5. Maturity of knowledge and technology, lessons learnt

Since high-level waste disposal activities have not started yet, there is little literature and technical documentation (apart from general presentations and position papers in seminars and workshops) on retrievability issues, and practical experience has so far been limited to "blank tests" (i.e. retrieval tests with dummy NWP).

The international examples listed in Chapter 3 are the main source of (partly proprietary) information available and provide an overview of the main technical achievements in this field.

Retrievability concerns and potential remedial solutions are furthermore customised to fit site specific situations (disposal set-up, nature of waste, nature of contamination, environmental data, etc.).

Furthermore, the WIPP and Asse Mine cases do not represent the typical experience, as they were planned in good faith without the intention of taking retrievability into account. Besides, the WIPP and Asse Mine cases show that there are no "off-the-shelf" remedial solutions and that many factors (other than technical or scientific) and actors are affecting the decision-making process and may lead to different choices: retrievability or reversibility can prevail.

6. Limits and uncertainties of retrievability

All approaches that precede the retrievability decision aim to reduce uncertainties on the state of waste packages, disposal cells, EBS and DGR openings. Some aspects of retrievability are discussed here, as no consensus among WMO experts in this area is known or has yet been reached. These aspects relate to the need for and the extent of the retrievability capacity demonstration. The answers may vary according to the disposal configurations, the environmental conditions and the schedule of operations.

- Q1: Should retrievability tests be carried-out after the start-up of disposal operations, i.e. with some real radioactive packages emplaced in the disposal cell (at Level 2 of the NEA retrievability scale), hence with real radioprotection concerns?

  As long as mechanical equipment used for the emplacement of NWP is also used for reversal operations, a retrievability test seems relevant and can be planned in the early stage of disposal (it can be one test amongst many others planned during the facility start-up campaign). This reversal test may or may not be "geographically extended" out of the disposal vault/deposition hole and may imply a NWP trip "back to the surface facility" where it was conditioned. The retrievability test is an opportunity to check the performance of the monitoring sensors and of the various inspection robots displayed in real radioactive conditions and to develop operators' experience in troubleshooting. The "right number" of retrieval cases to be tested (e.g., one NWP only or conversely a few) remains to be discussed by the WMO and the regulator and is specific to each disposal configuration.

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If carefully planned and scheduled, retrievability tests at Level 2 of the NEA scale are relevant. They may contribute to improve operators' know-how by training. They are a potential asset to gain confidence in the WMO's safety procedures and should support a decision to proceed with further disposal. The retrievability tests and their outcomes can also be a part of a "DGR Pilot Phase" (envisaged by various WMOs) at this early stage of the DGR life, which would extend over a period of time (a few decades) and allow stakeholders to form an opinion on future actions.

- Q2: Should retrievability demonstrations with real NWP be implemented only at early stage (a few months) of Level 3 of the NEA retrievability scale (disposal cell/deposition hole "freshly" sealed) or also at a later stage of stay (i.e. after a few decades)?

  At Level 3, the disposal cell is sealed by a buffer material (most of the time a clay-like material such as bentonite), which is positioned near the emplaced packages.

  In the Finnish and Swedish disposal configurations, the canister is surrounded by compacted bentonite blocks located in vertical deposition holes in a backfilled tunnel. The capacity to deconstruct a complete EBS has been/is being demonstrated with dummy NWP. The bentonite behaviour (a swelling material) is highly influenced by the crystalline formation water ingress. As long as the bentonite blocks stay dry and compacted, their safe mechanical removal is relatively easy, and the further recovering of the canister is also possible. At this stage, a retrievability demonstration with real NWP can be considered if this is of interest.

  After a certain lapse of time (varying with the hydrogeological conditions prevailing in the deposition holes and in the tunnel) the progressive water inlet will transform the compacted bentonite blocks in "soft clay", sticking to the environment (rock walls, NWP surfaces). The mechanical devices developed for positioning the blocks and the canisters become less efficient for recovery and new solutions are to be developed to clean and evacuate the swelling clay before accessing the canisters. The operational protocol becomes complex and radiation hazards are increasing. At this stage, considering the phenomenological situation, it does not look sensible or reasonable to implement a retrievability test with real NWP.

  In the French disposal configuration, considering the important waste inventory (hence the number and variety of packages), the size of the horizontal concrete lined intermediate-level disposal vault is significant (decametric diameter, hectometric length). Subsequently, the time needed for a complete vault filling with hundreds of NWP will take decades and will be a part of the Cigéo Pilot Phase. At the end of such a Pilot Phase, a decision-making process will take place before sealing the vault or not and the disposal activities are continued or not. If the decision is made to seal the vault,, it would be surprising to plan a retrievability test for this vault (such action would take years).

- Q3: Does it still make sense to evaluate effective retrievability capacity at Level 4 (Disposal zone sealed) or Level 5 (DGR entirely sealed and backfilled) of the NEA scale?

  The extent of work apprehended to reopen the DGR openings, to dismantle the backfills and the various EBS, to recommission the facility functions and equipment (mine and nuclear ventilation, mine and process equipment, control and monitoring, etc.) is extremely significant (in terms of duration and cost) and probably greater than the effort associated with the initial project. The potential recovery of degraded NWP induces additional needs and special dispositions (decontamination, reconditioning of packages, surface storage, etc.). Even if assessed, contamination and explosion hazards create complex operation conditions.

  At the end of the NWP disposal activities per se, a decision-making process will opt for the backfilling and closure or not. If closure and backfill are decided, it does not imply that the DGR must be reopened to test retrievability at Level 4 or 5. Even if the decision on retrievability ultimately lies with the stakeholders (government, law makers, NGOs, public, next generation, etc.), it does not seem reasonable to test the actual retrievability at this late DGR life stage.

7. Guidance, Training, Communities of Practice and Capabilities

This section provides a few links to resources, organisations and networks that can help connect people with people, focussed on the domain of retrievability.

Training
Invitation to participate in the retrieval of the Full-Scale Prototype Repository at Äspö HRL: the information flyer (www.skbinternational.se)
Active communities of practice and networks
No communities found, EURAD excepted
Capabilities (Competences and infrastructure)
Cf. Examples in Chapter 3

8. Further reading, external Links and references

Position papers on reversibility and retrievability and Pilot Phase

- "La récupérabilité des colis de déchets stockés dans Cigéo" 2021 www.andra.fr
- "Dossier de concertation sur la phase industrielle pilote de Cigéo" 2021 www.andra.fr
- "Retrievability Considerations for Geological Disposal" 15th November 2018 CoRWM doc. 3522

  https://www.gov.uk/government/organisations/committee-on-radioactive-waste-management

General documentation

- "Reversibility and Retrievability in Geologic Disposal of Radioactive Waste - Reflections at the International Level" NEA/OECD www.oecd-nea.org

- "Reversibility and Retrievability in Planning for Geological Disposal of Radioactive Waste" "Proceedings of the "R&R" International Conference and Dialogue 14-17 December 2010, Reims, France" NEA/OECD www.oecd-nea.org

- "Reversibility and Retrievability for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel" Final Report of the NEA R&R Project (2007-2011) NEA/OECD www.oecd-nea.org

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