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Review of Current Disposal Concepts concerning Measures for Retrievability

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Introduction

The detailed work programme for WP4 (Retrievability Desk Study) of Module 2 was discussed with the Project Officers on 27 September 2004. During this discussion it was agreed that the first task of this study would comprise a review of the current disposal concepts of the countries participating in the ESDRED projects from the perspective of retrievability. This Internal Memorandum records the findings of the review, and will inform the final deliverable for WP4 (Deliverable 2-D.4), scheduled for completion on 28.07.2006.

The approach taken to the review was to seek information from each of the partner organisations on the current national disposal concepts from the perspective of retrievability. The information provided for each country, as listed in appendix A, updates the information previously reported in the European Commission Reports EUR 19145 (*Concerted action on the retrievability of long-lived radioactive waste in deep underground repositories*) and EUR 21025 (*Thematic network on the role of monitoring in a phased approach to geological disposal of radioactive waste*).

Findings

A comparison of the disposal concepts relevant to ESDRED shows that there exists a wide range of national requirements concerning the extent to which the development of a waste disposal facility should be reversible prior to closure. For example, France has a policy requirement that each step of a repository development process, up to emplacement of the waste, is easily reversible. In contrast, Germany currently has no requirement concerning reversibility or waste retrievability in the context of any future geological disposal. Within this spectrum, most national disposal concepts aim to show that waste could be retrieved during the operational period of a repository, if so desired in future for whatever reason, though only limited provisions are intentionally incorporated in the design to facilitate easy retrieval of the waste.

The compilation of information focuses on potential retrievability enhancing measures, as previously discussed in EUR 19145. These include design and operational measures, together with monitoring activities associated with the three basic conditions that determine the extent of retrievability provided by a particular disposal concept, being:

- Accessibility of the waste packages;
- Confinement of the waste in the waste packages following emplacement; and
- Technical feasibility of retrieving the waste packages.

Potential design measures that enhance retrievability of waste prior to repository closure are primarily aimed at providing easier accessibility to the waste packages, particularly in clay and salt host environments, and/or providing an improved capability to retrieve the waste packages. Potential design measures in the first category include enhancing the stability of openings (e.g. by incorporating concrete or steel liners) and, in the second category, provision of easily removable buffer materials (e.g. in the form of pre-fabricated bentonite blocks). It is worth noting also that

the use of copper waste canisters, as envisaged by the Swedish and Finnish disposal concepts, ensures a high level of waste confinement for perhaps thousands of years, i.e. far beyond the operational period of a repository.

In most disposal concepts relevant to ESDRED these issues are still under consideration and definite positions may not be reached until countries are much closer to starting the development phase. Likewise, operational and monitoring strategies are still under development. For some disposal concepts, this may mean that access ways will remain open for perhaps several decades whilst greater levels of confidence in the disposal concept are achieved, e.g. as a result of ongoing monitoring of the disposal system. For other concepts, it is likely that intensive monitoring activities will be focused on a special facility, e.g. as envisaged for the Swiss concept, with closure of accesses to the main facility taking place relatively sooner, on the basis that the risk of neglect or even from deliberate intrusion is thereby significantly reduced.

appendix A Compilation of retrievability enhancing measures as currently envisaged in disposal concepts of ESDRED participants

A.1 Belgium (HLW / SF / Long-lived HLW)

A.1.1 *National policy on retrievability and national disposal concept*

National policy for long-term management of HLW and spent fuel is currently under review and it is likely to be several years before a definite position is established. It should be noted, however, that Government policy with regard to disposal of low-level waste is that a repository should be developed in a step-wise manner that allows for reversibility. Meanwhile, in developing a national disposal concept, the national waste management agency (ONDRAF/NIRAS) is considering options to facilitate easy retrieval of wastes (see EUR 19145).

A national concept for geological disposal of spent fuel and high and intermediate level waste in Boom Clay is currently under revision by ONDRAF/NIRAS following the 'SAFIR 2' interim safety assessment study [1] conducted in 2001. The current 'reference' design concept involves the canisters of spent fuel or high level waste first being placed in a carbon steel overpack and are then employed in a 'super container' that incorporates an annular concrete buffer material. The exterior of the super container comprises a stainless steel liner. It is envisaged that the super containers will be fabricated above ground and then employed in horizontal disposal cells, each gallery having a maximum length of about 200m. The gallery lining is made up of concrete wedge blocks and the space between the lining and the super container is filled with a granular backfill material.

The total quantity of heat generating waste / spent nuclear fuel that will be generated by the present-day Belgian nuclear power programme is estimated to be around 4,000 to 5,000 metric tons of heavy metal.

A.1.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
<p>(A) Design measures Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).</p>	<p>No special measures planned: but disposal galleries and other openings are lined with concrete and will therefore have significant inherent stability.</p>	
<p>Reduced number of packages per disposal cell.</p>	<p>No special measures.</p>	
<p>Control of environmental conditions/water inflow within open disposal cells, i.e. prior to installation of sealing plug.</p>	<p>Not planned: emplacement of waste package followed by immediate backfilling.</p>	
<p>Emplacement of waste canisters in disposal containers or overpacks.</p>	<p>Planned: SF and HLW canisters are placed in overpacks before emplacement in ‘supercontainers’ incorporating buffer material.</p>	
<p>Reduced distance from emplaced waste package to nearest access gallery.</p>	<p>Not planned: each depositing tunnel is tens of metres long.</p>	
<p>Enhanced stiffness and water tightness of metallic liners.</p>	<p>Not applicable: concrete-lined disposal galleries have significant inherent stability.</p>	
<p>Use of easily removable buffer formulations.</p>	<p>Under consideration: but use of granular backfill surrounding ‘supercontainer’ facilitates retrieval.</p>	
<p>Other</p>		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of backfill and sealing of disposal cell.	
Keeping depositing tunnels open.	Not applicable: concept of in-tunnel emplacement of HLW/SF canisters.	
Keeping access tunnels open.	Not yet decided.	
Keeping access shafts open.	Not planned: current intention is that access shafts are closed immediately following closure of the access tunnels.	
Other		
(C) Monitoring of package integrity parameters¹		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ² .	Not planned: emplacement of waste package followed by immediate backfilling.	
Other		

¹ i.e. aspects related directly or indirectly to confinement of the waste.

² Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not planned: pre-disposal experiments undertaken in separate URL.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.1.3 References

[1] ONDRAF/NIRAS, SAFIR 2: *Safety Assessment and Feasibility Interim Report*, NIROND 2001-2006 E, December 2001.

A.2 Finland (Spent fuel)

A.2.1 *National policy on retrievability*

In accordance with the Nuclear Energy Act all waste generated in Finland must be disposed of in Finland. Subsidiary regulations put in place by the nuclear inspectorate (STUK) require that the disposal concept for spent fuel should provide for retrievability of the waste canisters, though specify that long-term safety of a repository should not depend on monitoring. The specific requirements concerning retrievability will be clarified in future guidelines; meanwhile, it is clear that the current national concept for disposal of spent fuel offers a high degree of retrievability, particularly in view of the intrinsic robustness of the copper disposal canisters (see EUR 21025).

The Finnish national concept, developed by POSIVA, was considered in an EIA process in 2000, the Council of State took a Decision in Principle concerning the final disposal of spent nuclear fuel at Olkiluoto in Eurajoki. Parliament ratified the decision nearly unanimously in May 2001.

In 2002, a Decision in Principle was taken to construct a new nuclear power plant unit in Finland. At the same time, a Decision in Principle was taken on the extended construction of a final disposal facility for spent nuclear fuel in such a way that the spent fuel from the new plant unit can also be disposed of in the facility. The effect of the new reactor has been included, so that the amount of the spent fuel for disposal will be about 5800tU. The technical plan for the disposal of spent fuel in a crystalline host rock is based on the KBS-3 concept, as in Sweden. Spent fuel elements are packaged in a double metal canister consisting of an inner container of cast nodular iron and an outer hull of copper. The canisters will be emplaced at a depth of 400 - 700 metres in the bedrock, using emplacement holes drilled in the floors of tunnels. The space between the canister and the host rock will be filled with compacted bentonite. The tunnels will be backfilled with a mixture of crushed rock and bentonite.

The total quantity of spent nuclear fuel that will be generated by the present-day Finnish nuclear power programme is estimated to be around 4,000 metric tons of heavy metal.

A.2.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	No special measures planned but inherent high geometric stability.	
Reduced number of packages per disposal cell.	No special measures: but 6 - 11m distance between waste canisters in tunnel.	
Control of environmental conditions/water inflow within open disposal cells.	Not planned: immediate placement of bentonite buffer in disposal cell.	
Emplacement of waste canisters in disposal containers or overpacks.	Not applicable: copper canisters are inherently highly resistant to corrosion.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned: each depositing tunnel is about 250m long.	
Enhanced stiffness and water tightness of metallic liners.	No metallic liner planned: due to inherent geometric stability of disposal cell.	
Use of easily removable buffer formulations.	No special measures: feasibility of remote removal of bentonite and canister transfer into a radiation shield will be demonstrated.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of buffer and sealing of disposal cell.	
Keeping depositing tunnels open.	Not planned: immediate backfilling and plugging after emplacement of all waste canisters.	
Keeping access tunnels open.	20 - 40 years.	
Keeping access shafts open.	Not planned: immediate backfilling of access shafts following plugging of access tunnels.	
Other		
(C) Monitoring of package integrity parameters³		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ⁴ .	Not planned: immediate placement of buffer and sealing of disposal cell.	
Other		

³ i.e. aspects related directly or indirectly to confinement of the waste.

⁴ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not planned.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.2.3 References

- Posiva Oy, *The final disposal facility for spent nuclear fuel: Environmental Impact Assessment Report, 1999.*

A.3 France (HLW / SF / Long-lived ILW)

A.3.1 National policy on retrievability

The French Act no. 91-1381 of 30 December 1991 outlined a requirement for 15 years of research into options for management of high-level and/or long-lived radioactive waste, including the possibility for reversible or irreversible disposal in deep geological formations. More recent Government policy statements have given emphasis to the need for reversibility and have directed that the research now being conducted in the URL at the Meuse/Haute-Marne site should be concerned specifically with the reversibility and safety of a potential radioactive waste repository (see EUR 19145). It is planned that a definite policy for waste management will be decided in 2006 and will be set down in legislation.

The French national concept is being developed by ANDRA in parallel with the ongoing research studies concerning the suitability of the Callovo-Oxfordian clay host rock at the Meuse/Haute-Marne site. The current intent is that Category C waste packages, containing vitrified high-level waste, are placed in carbon steel overpacks and then transported from the surface in reusable shielding casks. The disposal canisters are placed in horizontal drifts (disposal cells), each about 40 metres in length, by a remotely operated pushing robot. The drifts are steel lined to facilitate reversibility. Each drift will contain a maximum of 22 waste packages. The main reasons for adopting an overpack for vitrified Category C waste packages are to protect the package during the thermal phase and to contain the medium-lived radionuclides. A bentonite based buffer material could be envisaged around the packages (the case considered in the ESDRED project). The packages are introduced into the disposal tunnel after this buffer has been emplaced. This buffer can be installed inside a metal perforated liner that covers the walls of the drift (cell). A long-term isolation plug made of bentonite closes each disposal cell.

Category B (containing medium levels of activity) waste disposal is planned in horizontal cavities, in which the cross section dimensions (10 to 12m) and length (up to 250m) are greater than for Category C waste, since heat generation is less an issue. To construct an engineered barrier around category B packages, concrete provides a chemical trap for actinides, supplemented for the most active waste by a plug closing the entrance to each disposal tunnel. The cross section shape of the disposal cavity could be a square section (the cavity walls being lined with cast in place concrete).

Note 1: For the option of disposal of Spent Fuel (SF), the packages can be placed in horizontal drifts, similar in principle to C waste drifts. A bentonite buffer then would also be used as in the SF waste disposal concept (where it is only an option).

Note 2: The total quantity of Category C and Category B wastes that will be generated by the present-day French nuclear power programme is estimated to be around 80,000m³ for B waste (195,000 primary packages) and 6,500m³ for C waste (36,000 primary packages), should all the Spent Fuel produced by the existing Nuclear Plants be reprocessed.

A.3.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
<p>(A) Design measures Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).</p>	<p>Under consideration: C and SF disposal cells are steel lined and other openings are lined with concrete and will therefore have significant inherent stability. Sizing of excavations for optimal stability and further enhancement of linings is under consideration.</p>	<p>Dimensioning of steel liner and concrete walls are still to be optimised.</p>
<p>Control of environmental conditions/water inflow within open disposal cells.</p>	<p>No special measures envisaged.</p>	<p>Water inflow will be very limited (argillite is a quite impervious rock) and ventilation will help.</p>
<p>Emplacement of waste canisters in disposal cells.</p>	<p>Planned: SF and HLW canisters are placed in overpacks before emplacement. In addition, a few centimetres of clearance will be maintained between disposal packages outer diameter and the liner inner diameter to facilitate retrieval.</p>	<p>A galvanic effect and a corrosion type bonding between 2 adjacent metallic parts could be prevented by inserting a ceramic coating on one of the parts.</p>
<p>No backfilling before sealing.</p>	<p>Under consideration: use of pre-fabricated bentonite rings and of a removable plug. Long-term isolation plug installed after completion of disposal package emplacement.</p>	<p>For retrievability purpose, the steel inner sleeve installed inside the buffer rings will protect the waste package from the swelling phenomena over a long period of time.</p>
<p>(B) Operational measures Keeping disposal cells open.</p>	<p>Under consideration: as long as the cells walls are stable, without intervention (up to 200 years).</p>	
<p>Keeping depositing tunnels open.</p>	<p>Under consideration: at least 100 years without intervention.</p>	<p>Lifetime could be extended with possible maintenance.</p>

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
Keeping access tunnels open.	Under consideration: at least 15 years, up to 100 years.	Maintenance possible.
Keeping access shafts open.	Under consideration: at least 100 years.	Maintenance is carried out.
(C) Monitoring of package integrity parameters⁵		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ⁶ .	Under consideration: parameters to be monitored may include temperature, air moisture, degree of saturation of the backfill, gas amount, chemical composition of water.	
Other		
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements) for cells, drifts & shafts.	No specific requirements: but mechanical stability of rock walls and supports will be monitored prior to backfilling (load on drift liner and steel inner tube), including the evolution of clearances.	No impact on waste retrievability as long as the inner sleeve is stable.
Extent of resaturation in backfilled disposal cells.	Under consideration: but further development of instrumentation needed to facilitate remote monitoring after sealing of disposal tunnel.	Very slow resaturation.
Ambient conditions in repository (e.g. temperature and radiation).	Under consideration: repository will be monitored prior to sealing and possibly after sealing.	Access galleries mainly are concerned.

⁵ i.e. aspects related directly or indirectly to confinement of the waste.

⁶ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow retrievability operations.	Not planned: since these equipment will be stored outside the cells & as such is easily maintainable.	
Other		

A.3.3 References (in French)

- Dossier 2005 *Tome Architecture et gestion d'un stockage – Chapitre 10.*
- CRP HAVL 040028-1V2 : *Analyse des niveaux de réversibilité d'un stockage en formation argileuse profonde – Site de Meuse/Haute-Marne.*
- ANDRA 2004 – *Conception, construction et fermeture des alvéoles de déchets B ; Rapport ANDRA N° C.NT.ASTE.04.0510.*
- ANDRA 2004 – *Conception, construction et fermeture des alvéoles de déchets vitrifiés et de combustibles usés, Rapport ANDRA N° C.NT.ASTE.04.0511.*
- ANDRA 2004 – *Récupération des colis de stockage de déchets B et C et de combustibles usés, avant et après scellement de l'alvéole. Rapport ANDRA N° C.NT.ASTE.04.0506.*

A.4 Germany (Gorleben⁷ disposal concept for HLW/SF/Long-lived ILW)

A.4.1 National policy on retrievability

National policy for long-term management of radioactive waste is currently under review. To date, national legislation and regulations do not require that radioactive waste should be retrievable following disposal, rather that disposal facilities should be constructed in such a way that their safety is not dependent on monitoring and do not require ongoing maintenance (see EUR 19145). The advisory group AkEnd, which has advised the Government with regard to set up a new site selection process, confirmed this position.

The German national concept for disposal of heat generating waste was developed assuming that the host environment would be the salt dome located at Gorleben. Following a consensus between the German Government and the nuclear utilities in June 2000, a moratorium was placed on the further site characterisation programme for a period of at least 3 up to at the most 10 years, to allow for clarification of issues related to disposal in salt in general, and to the Gorleben site in special, raised by the Federal Government. Thereafter, according to the consensus agreement, the site exploration at Gorleben is to be continued. In a different field of action the Ministry of the Environment announced its political intention of disposing of all radioactive waste in Germany in a single repository, to be available at about 2030. The search for the site for this repository should be carried out following the recommendations of the AkEnd.

The following boundary conditions were applied on the design for a repository of heat generating waste in salt rock formations:

- Spent fuel conditioning in self-shielding POLLUX-casks and cask disposal in horizontal position in blind drifts of a length up to 200m at the 840m level;
- Disposal of unshielded vitrified HLW canisters or direct disposal of spent fuel in unshielded canisters in boreholes in blind drifts with a depth of 300m or 30m (from the 840m mine level), respectively.

The total quantity of heat generating waste / spent nuclear fuel that will be generated by the present-day German nuclear power programme is estimated to be around be around 24,000m³ [2].

⁷ Investigations at Gorleben were suspended in 2000 pending a review of the national strategy for disposal of radioactive waste.

A.4.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	No special measures planned: but drifts expected to remain stable for at least 100 years.	
Reduced number of packages per disposal cell.	No special measures.	
Control of environmental conditions/water inflow within open disposal cells.	Not planned: emplacement of waste package followed by immediate backfilling.	
Emplacement of waste canisters in disposal containers or overpacks.	Planned for SF: packages are conditioned in self-shielding POLLUX casks. Disposal of unshielded vitrified HLW canisters and optional unshielded canisters for spent fuel in boreholes.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned: each depositing tunnel is up to 200 metres long.	
Enhanced stiffness and water tightness of metallic liners.	Not applicable: unlined drifts expected to remain stable for at least 100 years.	
Use of easily removable buffer formulations.	No special measures: but re-excavation of crushed salt backfill poses no special technical difficulty as had been demonstrated in the BAMBUS project [3].	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: emplacement of waste package followed by immediate backfilling and sealing of disposal cell ASAP.	
Keeping depositing drifts open.	Not applicable: concept of in-drift emplacement of HLW/SF canisters.	
Keeping access drifts open.	0 – 5 years.	
Keeping access shafts open.	0 – 70 years (operational life time of the repository).	
Other	N.A.	
(C) Monitoring of package integrity parameters⁸		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ⁹ .	Not planned: emplacement of waste package followed by immediate backfilling.	
Other		

⁸ i.e. aspects related directly or indirectly to confinement of the waste.

⁹ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not applicable.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.4.3 References

- [2] Brennecke, Peter and Kugel, Karin: *Radioactive waste arising in the Federal Republic of Germany - 2000 Waste Inquiry-*, BfS - Federal Office of Radiation Protection, Salzgitter, January 2004.
- [3] EUR 20621: *Backfilling and sealing of underground repositories for radioactive waste in salt (BAMBUS II project)*, Final Report, European Commission, 2004.

A.5 Netherlands (HLW)

A.5.1 National policy on retrievability

National policy for long-term management of HLW is that it should remain in storage for a period of 100 years or more, by which time the level of heat generation will have diminished significantly. Although, there is no specific legislation or regulations dealing with final disposal after storage, Government policy statements indicate that waste should eventually be placed in a deep disposal facility, constructed in such a way that the waste is retrievable (see EUR 19145).

Although there is no immediate requirement to decide on the final design concept for disposal of heat generating wastes, national concepts have been developed by NRG, the national organisation concerned with nuclear-related research, for geological disposal both in salt and Boom Clay host environments. As regards the former, the repository is assumed to be constructed in a rock salt formation at a depth of approximately 800m. Each vitrified high-level waste container will be placed in an individual horizontal borehole drilled in the sidewalls of the horizontal galleries constructed between parallel access galleries. The boreholes are drilled at 10m intervals and each borehole will be about 4m deep. After placement of a canister in a borehole, the borehole will be backfilled with 3 pre-compressed rock salt plugs, each 1m long [4].

In the case of disposal in the Boom Clay host rock, a grid of galleries would be excavated in the clay layer, consisting of access tunnels and disposal tunnels. In the sidewalls of the disposal tunnels horizontal disposal cells will be excavated which have a similar geometry to those in the disposal concept for a salt environment, i.e. about 5m in depth. To facilitate reversibility it is envisaged either that the disposal cell would be lined with a watertight lining, or that the waste container would be placed in an overpack.

The total quantity (after some 100 years of prolonged storage) of heat and non-heat producing HLW that will be generated by the present-day Dutch nuclear power programme is estimated to be around 3,000m³.

A.5.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	Under consideration: openings will be designed such that they could remain open for more than 100 years.	
Reduced number of packages per disposal cell.	Under consideration: one package per disposal cell.	
Control of environmental conditions/water inflow within open disposal cells.	Not planned: emplacement of waste package followed by immediate backfilling.	
Emplacement of waste canisters in disposal containers or overpacks.	Under consideration (for clay host environment only): vitrified waste package would either be emplaced in an overpack or, alternatively, a watertight, corrosion-resistant lining would be used.	
Reduced distance from emplaced waste package to nearest access gallery.	Under consideration: maximum distance between disposal cell and access gallery about 100 metres.	
Enhanced stiffness and water tightness of metallic liners.	Under consideration (for clay host environment only): vitrified waste package would either be emplaced in an overpack or, alternatively, a watertight, corrosion-resistant lining would be used.	
Use of easily removable buffer formulations.	Not planned: but use of compacted salt plugs for salt host environment facilitates easy removal of backfill.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of backfill and sealing of disposal cell.	
Keeping depositing tunnels open.	Planned: depositing tunnels will remain open for at least 25 years, but it is intended that future operators are able to extend this period significantly.	
Keeping access tunnels open.	Not planned: access tunnels and shafts will be backfilled immediately after the depositing tunnel has been backfilled and sealed.	
Keeping access shafts open.	Not planned: access tunnels and shafts will be backfilled immediately after the depositing tunnel has been backfilled and sealed.	
Other		
(C) Monitoring of package integrity parameters¹⁰		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ¹¹ .	Not planned: emplacement of waste package followed by immediate backfilling.	
Other		

¹⁰ i.e. aspects related directly or indirectly to confinement of the waste.

¹¹ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not planned.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.5.3 References

[4] Ministry of Economic Affairs, *Retrievable disposal of radioactive waste in The Netherlands*, February 2001.

A.6 Spain (SF & HLW)

A.6.1 National policy on retrievability

National policy for long-term management of radioactive waste is currently under review and it is likely to be several years before a definite position is established. To date, retrievability is neither an official option nor a regulatory requirement for the final disposal of HLW and spent fuel. Nonetheless, in developing a national disposal concept, the national waste management agency (ENRESA) is considering options to facilitate easy retrieval of wastes for a period in the order of 100 years (see EUR 19145).

The currently envisaged design concepts assume that the disposal canisters will be disposed of into a mined-type repository, excavated at 500m depths for the granite option and 250m depths for the clay option. The HLW disposal area will consist of horizontal disposal drifts arranged in two separate and independent disposal areas for the granite option and one disposal panel for the clay option. Each disposal tunnel will have a diameter of 2.4m and a maximum length of 500m. Each disposal canister will be embedded in a 0.75m thickness buffer made of compacted bentonite blocks. To comply with a design temperature constraint of 100°C (maximum temperature) at any point of the bentonite buffer, a 35m separation between depositing tunnels and 2m separations between disposal canisters have been selected for the granite option, and respectively 50m and 2.5m for the clay option. For the granite option, excavated galleries and accesses will be backfilled with an 80/20 compacted mixture of sand and bentonite. For the clay option, all open cavities will be lined with concrete segments, and finally backfilled and sealed with compacted excavated clay.

The total quantity of heat generating waste / spent nuclear fuel that will be generated by the present-day Spanish nuclear power programme is estimated to be around 6,570 metric tons.

A.6.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	Under consideration: horizontal disposal galleries are designed to remain stable for extended periods of time.	
Reduced number of packages per disposal cell.	No special measures: horizontal disposal tunnels are planned to extend to a maximum length of 500 metres.	
Control of environmental conditions/water inflow within open disposal cells.	Not applicable: as disposal concept requires immediate emplacement of bentonite blocks and intermediate bentonite plug following emplacement of each package.	
Emplacement of waste canisters in disposal containers or overpacks.	Not planned: envisaged disposal canister for both SF and HLW is an unshielded carbon steel cylindrical container with a service life of more than 1000 years.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned. No special measures: horizontal disposal tunnels are planned to extend to a maximum length of 500 metres.	
Enhanced stiffness and water tightness of metallic liners.	Under consideration: rigid, non-perforated, liners to avoid problems of canister sticking in liners may replace perforated liners in disposal tunnels.	
Use of easily removable buffer formulations.	Under consideration: use of pre-fabricated bentonite blocks facilitates easy removal prior to swelling.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of backfill and sealing of disposal cell.	
Keeping depositing tunnels open.	Not applicable: concept of in-tunnel emplacement of HLW/SF canisters.	
Keeping access tunnels open.	0 - 5 years.	
Keeping access shafts open.	Not planned: current intention is that access shafts are closed immediately following closure of the access tunnels.	
Other		
(C) Monitoring of package integrity parameters ¹²		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ¹³ .	Not planned: emplacement of waste package followed by immediate backfilling.	
Other		

¹² i.e. aspects related directly or indirectly to confinement of the waste.

¹³ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not planned: pre-disposal experiments undertaken in separate URL.	
Ambient conditions in repository (e.g. temperature and radiation).	Under consideration: repository will anyway be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.7 Sweden (Spent fuel)

A.7.1 National policy on retrievability

Although there are no specific laws and regulations that requiring retrievability or monitoring of waste emplaced in a deep repository, the current national concept for disposal of spent fuel offers a high degree of retrievability, particularly in view of the intrinsic robustness of the copper disposal canisters. Regulations put in place by the nuclear inspectorate (SKI) require that any monitoring measures foreseen by the implementers should not impact on the safety of the repository (see EUR 21025).

The technical plan for the disposal of spent fuel in a crystalline host rock is based on the KBS-3 concept. Spent fuel elements are packaged in a canister consisting of an inner container of cast iron and an outer watertight copper shell. The repository is planned to be situated at a depth of about 500m, depending on conditions at the selected site. From a tunnel system, deposition holes are bored in which copper canisters with spent nuclear fuel are emplaced and surrounded with bentonite clay. The tunnels will be backfilled with a mixture of bentonite and crushed rock or other suitable material.

The deep repository will be built in two stages. In the first stage, approximately 10% of the spent nuclear fuel, i.e. about 400 canisters, will be emplaced. This initial disposal period is planned to start around 2017 and last for about 5 years, after which the experience gained will be evaluated. If the result of the evaluation is that continued deposition is suitable and acceptable, which is the expectation, the entire repository will be built (stage 2) and the activities will continue until all waste has been disposed of. As a logical consequence of the strategy of having an initial stage of waste emplacement, followed by a thorough evaluation, the ability to retrieve disposed canisters, if some aspect should prove to be unacceptable, is a requirement of the strategy.

The total quantity of spent nuclear fuel that will be generated by the present-day Swedish nuclear power programme is estimated to around 9,000 metric tons¹⁴.

¹⁴ The amount of spent from the Swedish programme is about 9,000 tons HM, of which 6,900 tons is BWR fuel and 2,100 tons from PWR fuel. There is also some 23 tons MOX fuel and 22 tons from the Ågesta reactor.

A.7.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	No special measures planned: but inherent high geometric stability.	
Reduced number of packages per disposal cell.	No special measures: but 6m distance between waste canisters in same tunnel.	
Control of environmental conditions/water inflow within open disposal cells.	Not planned: immediate placement of bentonite buffer in disposal cell.	
Emplacement of waste canisters in disposal containers or overpacks.	Not applicable: copper canisters are inherently highly resistant to corrosion.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned: each depositing tunnel is about 300m long and 40m between depositing tunnels.	
Enhanced stiffness and water tightness of metallic liners.	No metallic liner planned: due to inherent geometric stability of disposal cell.	
Use of easily removable buffer formulations.	No special measures: feasibility of remote removal of bentonite and canister transfer into a radiation shield will be demonstrated.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of buffer and sealing of disposal cell.	
Keeping depositing tunnels open.	Not planned: immediate backfilling and plugging after emplacement of all waste canisters.	
Keeping access tunnels open.	25 - 40 years.	
Keeping access shafts open.	Not planned: immediate backfilling of access shafts following plugging of access tunnels.	
Other		
(C) Monitoring of package integrity parameters¹⁵		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ¹⁶ .	Not planned: immediate placement of buffer and sealing of disposal cell.	
Other		

¹⁵ i.e. aspects related directly or indirectly to confinement of the waste.

¹⁶ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored prior to backfilling.	
Extent of resaturation in backfilled disposal cells.	Not planned.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations.	Not planned.	
Other		

A.8 Switzerland (HLW, SF and Long-lived ILW)

A.8.1 National policy on retrievability

Current national policy with regard to long-term management of radioactive waste is outlined in the Nuclear Energy Law (2003). This is based on the concept of monitored geological disposal as proposed by EKRA (Swiss Expert Group on Disposal Concepts for Radioactive Waste). The Law foresees the disposal of radioactive wastes in a deep geological disposal facility where, after the emplacement, a period of monitoring will take place before the facility is closed (see EUR 21025).

Disposal of high level and long-lived waste is envisaged to be in a deep geological repository in an Opalinus Clay host environment [5]. The current concept is emplacement of HLW/SF in long horizontal tunnels and emplacement of long-lived intermediate level waste in drifts or small caverns in a separate part of the repository. Before emplacement, the waste packages are placed in an overpack (steel or copper/steel canister). Emplacement of a waste package in a disposal tunnel is followed by immediate backfilling and, after the tunnel is filled with canisters, it will be immediately sealed.

The total quantity of SF/HLW and long-lived ILW that will be generated by the present-day Swiss nuclear power programme¹⁷ is estimated to around 130m³ vitrified HLW (resulting from reprocessing), about 1,860 metric tons of heavy metal and around 8,000m³ LL-ILW.

¹⁷ These data refers to the 120 GW_{ea} – Case (assumption 40 years lifetime of existing nuclear power plants).

A.8.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	No special measures planned: but openings will be lined (operation and construction tunnels) or supported with bolts and mesh (emplacement tunnels) in accordance with operational requirements.	
Reduced number of packages per disposal cell.	No special measures.	
Control of environmental conditions/water inflow within open disposal cells.	Not planned: (1) because of the low hydraulic conductivity no water inflow is expected; (2) the environmental conditions (e.g. relative humidity) are controlled by ventilation; (3) emplacement of waste package followed by immediate backfilling.	
Emplacement of waste canisters in disposal containers or overpacks.	Planned: HLW/SF packages are placed in steel or copper/steel canisters with a welded lid.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned: each emplacement tunnel for SF/HLW is about 800 metres long.	
Enhanced stiffness and water tightness of metallic liners.	Not applicable: emplacement tunnels will be supported (bolts and mesh) in accordance with operational requirements.	
Use of easily removable buffer formulations.	No special measures: but conceptual designs have been developed for retrieval of canisters (using special equipment).	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	Not planned: immediate placement of buffer and sealing of disposal cell.	
Keeping depositing tunnels open.	Not applicable: concept of in-tunnel emplacement of HLW/SF canisters and ILW canisters.	
Keeping access tunnels open.	About 15 years in the main repository; access tunnels and ramp to control tunnels of the pilot repository are kept open for about 100 years.	
Keeping access shafts open.	Not planned: immediate backfilling of access shafts following plugging of access tunnels, but ramp giving access to the underground (e.g. to the observation tunnels) is kept open during the observation phase (assumption: up to 100 years).	
Other		
(C) Monitoring of package integrity parameters¹⁸		
Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry) ¹⁹ .	Not planned in main repository (emplacement of waste package followed by immediate backfilling) but will be undertaken in adjacent pilot facility.	
Other		

¹⁸ i.e. aspects related directly or indirectly to confinement of the waste.

¹⁹ Prior to sealing of disposal cell.

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(D) Monitoring of waste accessibility parameters		
Stability of openings (e.g. rock movements).	No specific requirements: but deformation of accessible openings will be monitored.	
Extent of resaturation in backfilled disposal cells.	Not planned in main repository: but will be undertaken in adjacent pilot facility.	
Ambient conditions in repository (e.g. temperature and radiation).	No specific requirements: but repository will be monitored prior to backfilling; in addition, the pilot repository will be monitored.	
Other		
(E) Monitoring of systems for waste retrieval		
Monitoring of equipment installed to allow reversibility of operations,	Not decided.	
Other		

A.8.3 References

[5] NAGRA, *Project Opalinus Clay: Safety Report*, Technical Report 0205, December 2002.

A.9 United Kingdom (Long-lived ILW)²⁰

A.9.1 National policy on retrievability

National policy for long-term management of radioactive waste is currently under review and it is likely to be several years before a definite position is established. Nonetheless, various Government policy statements indicate a preference that, in the event of geological disposal becoming the national policy, any repository should allow for monitoring of the waste after its emplacement and that the waste should be retrievable if that turns out to be necessary (see EUR 19145).

A disposal concept for geological disposal of long-lived intermediate level waste has been developed by the national waste management agency, Nirex. This concept provides a basis for the conditioning of wastes from power plant operation and from reprocessing of spent fuel. According to this concept, waste for disposal would arrive in either unshielded ILW packages (which are transported to the repository in reusable shielded transport containers) or self-shielded ILW/LLW packages. Packages would be transferred underground via a drift access tunnel. Once underground, unshielded ILW would enter an inlet cell where waste packages would be removed from the reusable transport containers where the waste would be transferred to one of the disposal vaults via a transfer tunnel. An overhead crane would then be used to emplace packages within vaults. Shielded ILW and LLW packages would be emplaced directly in the disposal vaults by a man-operated stacker truck.

The total quantity of SF/HLW and long-lived ILW that will be generated by the present-day British nuclear power programme is estimated to around 4,100 metric tons of heavy metal, 1,340m³ vitrified HLW (resulting from reprocessing) and about 165,000m³ LL-ILW.

²⁰ The United Kingdom has not yet developed a long-term concept for HLW.

A.9.2 Current strategy - tabulation

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(A) Design measures		
Enhanced stability of openings (e.g. disposal cells, access tunnels and shafts).	No special measures: but maintenance/refurbishment provisions if openings remain beyond 100 years.	
Reduced number of packages per disposal cell.	No special measures.	
Control of environmental conditions/water inflow within open disposal cells.	Environmental controls: proposed to manage vault environment and minimise corrosion of canisters and handling equipment (including temperature and humidity controls).	
Emplacement of waste canisters in disposal containers or overpacks.	Not planned: ILW will be packaged in stillages containing 4 x 500 litre drums or in 3m ³ boxes or drums. Some ILW/LLW packaged in 2m and 4m contact-handled boxes.	
Reduced distance from emplaced waste package to nearest access gallery.	Not planned: waste canisters are emplaced in 300m long vaults.	
Enhanced stiffness and water tightness of metallic liners.	Not applicable: waste canisters are emplaced in large unlined vaults.	
Use of easily removable buffer formulations.	Specially formulated cement grout: proposed to be emplaced before closure. The feasibility of remote removal of grout and canister recovery has been demonstrated in surface mock-up.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
(B) Operational measures		
Keeping disposal cells open.	0 - 100 years: taken to be the period during which emplacement measures could be reversed without significant additional features. Access for vault refurbishment would be required for longer periods with waste removed to replacement vault.	
Keeping transfer tunnels open.	0 - 100 years: taken to be the period during which emplacement measures could be reversed without significant additional features. Access available at all times other than when transporting waste.	
Keeping access tunnels open.	0 - 100 years: taken to be the period during which emplacement measures could be reversed without significant additional features. Accessible for maintenance at all times.	
Keeping access shafts open.	0 - 100 years: taken to be the period during which emplacement measures could be reversed without significant additional features. Accessible for maintenance at all times.	
Other		

Type of retrievability enhancing measure	Current strategy	Comments/Open issues
<p>(C) Monitoring of package integrity parameters²¹ Monitoring of environmental conditions in disposal cell (backfill temperature, water saturation, geochemistry)²².</p> <p>Other</p>	<p>Under consideration: immediate placement of buffer and sealing of disposal cell.</p>	
<p>(D) Monitoring of waste accessibility parameters Stability of openings (e.g. rock movements)</p>	<p>No specific requirements: deformation of accessible openings would be monitored prior to backfilling.</p>	
<p>Extent of resaturation in backfilled disposal cells</p>	<p>Not planned: backfilling proposed before closure.</p>	
<p>Ambient conditions in repository (e.g. temperature and radiation)</p> <p>Other</p>	<p>No specific requirements: but repository would be monitored (temperature and humidity) prior to backfilling.</p>	
<p>(E) Monitoring of systems for waste retrieval Monitoring of equipment installed to allow reversibility of operations.</p> <p>Other</p>	<p>Under consideration: crane system can be withdrawn from vault for accessible maintenance.</p>	

²¹ i.e. aspects related directly or indirectly to confinement of the waste.

²² Prior to sealing of disposal cell.

