National Monitoring Contexts
Country Annexes

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1. Introduction

1.1 Background to the MoDeRn Project

The successful implementation of a repository programme relies on both the technical aspects of a sound safety strategy, and scientific and engineering excellence, as well as on social aspects such as public acceptance. Monitoring has the potential to contribute to both of these aspects and thus to play an important role as national radioactive waste disposal programmes move forward towards a successful conclusion, i.e. safe and accepted implementation of geological disposal.

The role of monitoring through the staged implementation of geological disposal has been considered on an international basis through production of an International Atomic Energy Agency (IAEA) Technical Document (TECDOC) on monitoring of geological repositories (the IAEA Monitoring TECDOC) (IAEA, 2001) and by the European Commission (EC) within a Thematic Network on the Role of Monitoring in a Phased Approach to Geological Disposal of Radioactive Waste (the Monitoring ETN) (EC, 2004). These two documents have described how monitoring can support the implementation of geological disposal in a broad sense.

The EC Seventh Framework Programme “Monitoring Developments for Safe Repository Operation and Staged Closure” (MoDeRn) Project aims to further develop the understanding of the role of monitoring in staged implementation of geological disposal to a level of description that is closer to the actual implementation of monitoring.

Monitoring provides operators and other stakeholders with in-situ data on repository evolutions, to help manage construction, operation and/or closure activities, and may allow for a comparison with prior safety assessments. The project focuses on monitoring conducted to confirm the basis of the long term safety case and on monitoring conducted to inform on options available to manage the stepwise disposal process from construction to closure (including e.g. the option of waste retrieval). It thus provides information to inform necessary decisions. If, in addition, monitoring activities respond to stakeholder needs and provide them with understandable results, they will contribute to transparency and possibly to stakeholder confidence in the disposal process.

MoDeRn project partners (in Table 1-1 below) represent organisations responsible for radioactive waste management in the EU, Switzerland, the US and Japan as well as organisations having relevant monitoring expertise. Other partners offer substantial experience in researching how people interact with technology and finding ways to engage all stakeholders (e.g. civil society, experts, technical safety organisations, industry) in highly technical issues.

Table 1-1: List of MoDeRn Project Partners

Partner number	Partner full name	Short name	Country code (2-letter ISO code)
1	Agence nationale pour la gestion des déchets radioactifs	Andra	FR
2	Asociación para la Investigación y el Desarrollo Industrial de los Recursos Naturales	Aitemin	ES
3	DBE Technology GmbH	DBE TEC	DE
4	Empresa Nacional de Residuos Radioactivos S.A.	Enresa	ES
5	European Underground Research Infrastructure for Disposal of Nuclear Waste in Clay Environments	Euridice	BE
6	Nationale Genossenschaft für die Lagerung radioaktiver Abfälle	Nagra	CH
7	Nuclear Decommissioning Authority	NDA	UK
8	Nuclear Research and Consultancy Group v.o.f.	NRG	NL
9	Posiva Oy	Posiva	FI
10	Radioactive Waste Repository Authority	RAWRA	CZ
11	Radioactive Waste Management Funding and Research Center	RWMC	JP
12	Sandia National Laboratories	Sandia	US
13	Universiteit Antwerpen	UA	BE
14	University of East Anglia	UEA	UK
15	University of Gothenburg	UGOT	SE
16	Galson Sciences ltd.	GSL	UK
17	Eidgenössische Technische Hochschule Zürich	ETH Zurich	CH
18	Svensk Kärnbränslehantering AB	SKB	SE

The project is structured into six work packages (WPs). The first four WPs are dedicated to (i) analyse key objectives and propose viable strategies, based on both technical and stakeholder considerations; to (ii) establish the state of the art and provide technical developments to match specific repository requirements; to (iii) conduct in-situ monitoring demonstration experiments using innovative techniques; and to (iv) conduct a case study of monitoring and its integration into staged disposal, including specific scenario analysis aimed at providing guidance on how to handle and communicate monitoring results, in particular when these provide "unexpected" information. The fifth WP regroups all dissemination and outreach activities and the sixth WP is dedicated to consolidating project results into a reference framework on how monitoring may be conducted at the various phases of the disposal process.

1.2 Report Objectives

This document "National Monitoring Contexts - Country Annexes" and its companion report "National Monitoring Contexts – Summary Report" report on work conducted under project Task 1.1. The objectives of both reports are:

- To provide each project partner with the opportunity to present background information on the national context likely to influence repository system monitoring.
- To structure specific elements of national monitoring contexts in a set of societal and physical boundary conditions which may influence some of the upstream decisions for geologic repository monitoring.
- To develop an overview of these boundary conditions.
- To discuss how these boundary conditions may influence specific, national decisions on development and implementation of monitoring programmes.
- To provide a basis for a shared view on the development and implementation of a monitoring programme, including the required flexibility for its application in various national monitoring contexts.

In a first step, brief introductions of the various national monitoring contexts were provided in this "Country Annexes" report. To allow for some level of comparison between these, they were structured according to several "boundary conditions" to monitoring, which are introduced in greater detail in the companion "Summary Report". In a second step, these country specific overviews were analyzed to develop the companion "Summary report".

1.3 Report Structure

The report is structured as follows:

- Section 1 describes the background to the National Monitoring Contexts reports, the objectives of these reports and the structure of this "Country Annexes" report.
- Sections 2 through 13 provide an overview of background information for 12 national contexts, each likely to influence decisions and developments relevant to repository system monitoring in the corresponding country. Each was provided by the organization representing its nations program within this project.

2. French National Context (Andra)

This French Annex to the “National Monitoring Contexts” report provides a brief overview of how various societal and physical considerations might influence decisions pertaining to and the development of a repository monitoring programme. Andras’ current progress towards the development of such a monitoring programme is summarized in (Andra, 2010a).

2.1 Societal Aspect

2.1.1 Legal and regulatory framework

Prior to the most recent (2006 and 2008) legal and regulatory framework, research on geological disposal considered the 1991 law and 1991 safety rule. The following sections highlight a few of the items specified in the historical and most recent framework and provide first thoughts on how an analysis of associated requirements might lead to the identification of either generic or at times more specific monitoring objectives.

A number of additional regulations must be taken into account, for example the *Code du Travail* and *Code de l’Environnement*. The potential transfer of regulations relevant to mining operations and to subsurface infrastructure (tunnels) is currently being investigated. Further safety regulations address specific issues. For example, the current French water protection regulation forbids maintaining boreholes open and in operation over a length of time – ongoing hydrogeological monitoring would thus require a motivated exception to this regulation. Regulation concerning seismic activity has implications on design requirements – given the long life time and aging of subsurface structures, this may suggest a need to monitor structure and construction material aging. Regulation on external inundations, including from heavy rain fall and from aquifers, are currently revisited – this may give rise to a requirement to monitor potential sources of water inflow into the repository. Regulations on fire are currently analysed to evaluate similarities between fire prevention in mines/tunnels and nuclear installations. A specific regulation on ventilation systems designed to protect against radionuclide dissemination is currently being analysed in combination with other relevant regulation, to provide Andra with ventilation design and operation guidelines. Finally, the application of an explosive atmosphere (ATEX) regulation to the repository is being developed, taking into account European and French regulations as well as French and international Norms. From this, to manage the risk of hydrogen accumulation, specific monitoring objectives related to the presence, concentration and production rate of hydrogen within disposal drifts, and their spread via ventilation can be derived.

2.1.1.1 The 1991 Waste Act and Fundamental Safety Rule

The former, December 1991 French Radioactive Waste Act (Loi n°91-1381) established Andra and charged it with operations and long term management of radioactive waste. It also charged Andra with conducting a feasibility study on reversible or irreversible geological disposal of radioactive waste, a report on which was presented in 2005. There was a progressive shift of preference given to a reversible concept, and in 1998 the government reemphasized the importance to account for reversibility within the feasibility study.

In June 1991, a Fundamental Safety Rule (RFS III.2.f.) on deep geological disposal of radioactive waste was established. It prescribes a set of objectives that must be taken into account to ensure repository safety after the operational period. It treats (i) repository fundamental safety objectives, (ii) repository design basis related to safety, (iii) safety demonstration methodology. The Rule distinguishes between a safety analysis conducted for a reference situation, which takes into account all predictable repository evolutions based on certain and high probability events, and alternate scenarios, which take into account unlikely events of natural or human origin.

The fundamental safety objective is the short and long term protection of man and the environment, requiring that the repository limits any impact to a level “as low as reasonably possible”. A radioprotection criterion is set for dose equivalents, limiting radiological impact of the repository in the reference situation (i.e. in a long term evolution scenario regrouping all certain or highly likely events) to 0.25 mSv/year.

The rule provides for a number of repository design basis linked to safety, specifically for the waste disposal packages, the engineered barriers (other than waste packages), technical criteria for site selection, and for the overall concept.

Already some monitoring objectives can be explicitly or implicitly inferred from the requirements and criteria set in the Rule. For instance, establishing that site hydrogeology and geologic stability are commensurate with repository safety can be directly linked to a monitoring activity, first to be conducted during site investigation[1]. It may be pursued during operations and possibly after closure for confirmatory purposes and/or to monitor any evolutions related to repository construction, operation and closure. The requirement to know disposal package content (chemical and radiological content), its physical characteristics and properties important to initial confinement performance (mechanical and temperature resistance, potential of degassing, chemical interactions…) also directly leads to the development of monitoring objectives, first to be conducted prior to waste acceptance. It may be pursued in temporary storage, to establish some of the property evolutions over a few years or decades. Design requirements on (other) engineered barriers, such as ensuring that residual voids are adequately filled or that waste heat is evacuated, might also give rise to specific monitoring objectives. Finally, the requirement to limit perturbations of the host rocks’ confinement properties suggests some confirmatory in-situ monitoring activity.

The rule stated that post-closure safety evaluations should (i) justify the favourable performance of all confinement barriers, (ii) evaluate the disturbances created by repository construction and operation and verify they remain acceptable, (iii) evaluate future repository behaviour and that predicted doses remain acceptable.

The first two could give rise to in-situ monitoring objectives, results of which would feed into any future (i.e. post license application) updates of safety evaluations. The latter is based on predictive repository evolution models and could also give rise to monitoring objectives, whose aim is to progressively reduce uncertainties in the models.

Annex 1 to this safety rule also provides a number of general orientations on site investigations, first for surface based investigations, second for sub-surface, URL based investigations. In addition, Annex I explicitly calls for instrumentation to be emplaced to monitor the site evolution during repository operation. Given the long operational time and the perturbations induced during this period, it is considered unavoidable to foresee instrumentation adapted to monitor parameter evolutions for the site and the structures. This instrumentation shall be emplaced as early as possible, to ensure monitoring of site and structures not only during, but also prior to the operational period. Among others, should be monitored:

- Site piezometry

[1] While site investigation includes a variety of monitoring activities, it should be noted that the MoDeRn project focuses attention on any monitoring that would be conducted to confirm predicted/expected behavior of the repository. The project does therefore not further develop monitoring activities conducted to establish baseline conditions.

- Movements and, more generally, behaviour over time of structures remaining open for a long time (some site investigation boreholes, access shafts, galleries)
- Seismic movements
- Thermal evolutions and their consequences (stress, displacements, fracturing…)

In a second Annex, the safety rule presented a list of situations to consider for safety evaluation.

2.1.1.2 The 2006 Programme Act on the Sustainable Management of Radioactive Waste

The more recent legal framework was set with the 2006 Programme Act on the sustainable management of radioactive materials and wastes (Loi n°2006-739). Within its content, a few items may have direct consequences on monitoring objectives. The Act mandates that the deep geological disposal be reversible for a period that can be no less than one century. It also establishes that only a further Act can authorise a closure of the repository.

The reversible approach includes a structured decision-making process pertaining to progressive repository construction, operation and closure, where decisions are based on available information. Monitoring will contribute to the information. The Act specifies that a dedicated "reversibility law" will be proposed in 2015, after submission of a license application. It is Andra's responsibility to include a reasoned technical development responding to the overall reversibility requirement, including the proposal of a reasoned use of monitoring to inform the reversible management process.

A similar argument on potential monitoring needs is suggested in relation to the expert recommendations and parliamentary debate preceding the "repository closure" Act (called for possibly sometime in the 21st century, given the reversibility minimum duration requirement). These will likely be interested in basing their recommendations and decisions on actual knowledge of the repository condition and predicted evolutions after closure, and thus on information obtained from in-situ monitoring.

In a separate Article the Act calls for setting up a Local Information and Follow-up Committee (CLIS). This group has recently shown an increased interest in repository monitoring issues, especially as related to the technological potential for monitoring over long (century-scale) time frames (cf. §2.1.3) The Act also calls for a public debate to be prepared in 2012 in relation to site selection.

2.1.1.3 The 2006 Transparency and Nuclear Security Act

At the same time, parliament voted the June 2006 Act on Transparency and Security in the Nuclear Field (Loi n°2006-686). It introduces a new legal framework and establishes the Nuclear Safety Authority (ASN, Autorité de Sûreté Nucléaire) as an independent administrative authority. Its mission is to regulate nuclear safety and radiation protection in France. It is thus responsible for regulation and control of all Base Nuclear Installations, including radioactive waste management. The Institute for Radioprotection and Nuclear Safety (IRSN, Institut de Radioprotection et de Sûreté Nucléaire) provides the technical support to ASN during evaluation of applications.

Principles for protection are set out in the Public Health Code and in the Environmental Code and all activities comprising a risk of personal exposure to ionising radiations must comply with these principles. The Transparency as set forth in this Act consists in a set of measures adopted to ensure the public's right to reliable and accessible information on nuclear security. There is a right of any person to obtain information on risks related to ionising radiations associated with a given nuclear activity. Licensees of Base Nuclear Installations must provide an annual report, which will be publicly disclosed. Local Information Committees are set up at all sites. A High

Committee for Transparency and Information on Nuclear Safety is created, to be an information and debate body on risks related to nuclear activities.

The Act stipulates that the creation of a Base Nuclear Installation cannot be authorized unless the licensee proves that technical or organisational measures are likely to prevent or limit sufficiently the risks or drawbacks which the installation presents. For the geological disposal, such measures must also be proposed for maintenance and for surveillance after final shut down. While not technically explicit, the latter nevertheless points to an obligation to provide for some form of post-closure monitoring. Additionally, the mention of maintenance suggests the need to first detect any degradation in performance, prior to deciding that such maintenance is needed, and thus also suggests some need for monitoring.

The Act also specifies regular safety reviews, in which the situation of the installations must be evaluated. Such a review must allow the situation of the installation to be appreciated and must make it possible to update the assessment of risks or drawbacks the installation represents. This should be done by taking into account among other things the state of the installation. After the review, the licensee sends the Nuclear Safety Authority a report including the conclusions of the review and the suggestion of provisions to remedy observed anomalies or to improve safety of the installation.

An interpretation of these requirements suggests that they will likely call on some amount of in situ data allowing to appreciate the situation of the repository installations and to serve as a basis for an iterative update of the safety evaluation. It is not explicitly stated if long term safety assessments are also to be reviewed periodically, in line with the operational safety. The assessment of risks and drawbacks called for does, however, suggest that long term safety is to be included in such a review. This would further suggest that monitoring may be required to confirm and/or enhance understanding of in-situ evolutions that are relevant to long term safety. In any event, some feedback from monitoring activities are likely to be required prior to obtaining a closure authorisation, to prevent or limit sufficiently the risks or drawbacks they can present for security, public health or protection of nature and the environment.

The decree authorising closure will also prescribe a number of operations to be borne by the licensee after closure. A specification of prescriptions on water sampling from the installation and on discharged radioactive substance sampling is given, where necessary.

The Act states that when the installation has entered a (post-closure) surveillance phase, the Nuclear Safety Authority submits to the approval of the responsible Ministers the decision to declassify the installation.

2.1.1.4 The 2008 Safety Guide for Geological Repository

The Safety Guide (Autorité de Sûreté Nucléaire, 2008) is an update of the 1991 RFS III.2.f. It is applicable in relation to the post-closure, long term safety. It defines the objectives that must be considered from as early as site investigation and for the design to ensure post closure safety. This Safety Guide is consistent with relevant articles in the Environment Code and the Public Health Code, the 2006 Sustainable Waste Management Act. It takes into account the results from work carried out within the framework of the 1991 Waste Act, as well as recommendations provided by competent international organizations (IAEA, NEA, IRPC). Andra's overall analysis and approach to designing and operating a safe repository is provided in (Andra 2010b).

This section provides a brief outline of some of the items addressed in the Safety Guide, with special emphasis on issues that may be directly or indirectly related to monitoring.

Spent fuel is not considered radioactive waste for as long as it can be retreated to extract valuable material or to reduce its polluting or danger aspects, with available technical and economical conditions.

Three categories of components are considered playing a role in safety: The waste disposal packages (radioactive waste conditioned by the producer and potentially reconditioned in an overpack prior to disposal), engineered barriers ensuring closure of repository cavities and boreholes, backfill and seals of infrastructure and surface-depth infrastructure, and host rock.
Geological disposal has to be carried out while respecting the principle of reversibility. Reversibility assumes adapted modes of operation and means of monitoring of the installations.
The control of nuclear substances has to be considered from the design phase as defined in the Defense Code. Any control measures, however, shall not compromise operational safety and post-closure safety.
The protection of public health and the environment shall not rely on surveillance or institutional control after repository closure, as these cannot be maintained with certainty for longer than a limited time frame. Post closure safety is to be ensured passively, without any need for intervention.
The site characteristics, the siting of repository structures, the design of manmade components (disposal packages and other engineered barriers) and the quality of their manufacture are the basis of safety.
During the operational phase, radioprotection criteria are those applied to any base nuclear installation, consistent with the work code (for worker protection) and the public health code (for general public protection).
In a reference scenario regrouping all certain or higly likely events, effective dose calculations for post closure safety should not exceeed 0.25 mSv/yr. Calculations are based on models of repository evolutions, especially of disposal package and other engineered barrier degradation, and of water based transfer of radionuclides as well as radionuclide gas transfer. Over the first 10000 years, dose calculations should not lead to values exceeding said limit. Otherwise, the concept must be revised or remaining scientific uncertainties reduced to verify the respect of such limit. After 10000 years, this value serves as a reference for the verification of safety.
The Safety Guide also requires the evaluation of alternate scenario, in which some overall guidance is given on how the results of corresponding dose calculations should be evaluated.
The Safety Guide outlines a number of design bases linked to safety. It presents safety principles and safety functions; specific aspects to be considered for disposal packages; criteria for site selection (stability, hydrogeology, minimum depth, absence of subsurface resources) as well as adequate thermal, mechanical and geochemical properties; functions of engineered barriers to be specified consistently with expected performances of disposal packages and host rock; general guidelines for the overall repository system; and the requirement of a monitoring program.
The various principals, criteria and recommendations given in above mentioned design bases can be further analyzed to deduce a number of monitoring objectives (for example related to a maximum temperature criterion of 100°C). In addition, special attention is drawn to the development of techniques and means of control ensuring the quality of disposal package and engineered barrier construction and justifying the level of confidence that these can perform their expected functions.
The section calling for a monitoring program provides the following guidelines. A monitoring program of the installations is to be implemented during construction and until closure of the installations. Some of the monitoring approaches could also be pursued after closure of the installations. The need to implement this monitoring must be taken into account as early as the design of the disposal.
In addition to contributing to the installations' operational safety, the monitoring programs' objective is to follow the evolutions of a set of parameters characterising the state of installation components as well as of the geological environment, and the principle phenomena responsible for these evolutions. The monitoring program based on updating scientific knowledge must show

that these phenomena were anticipated and remain under control. It contributes the information needed for the management, the operation and the reversibility of the installation.
The means used for monitoring shall not reduce the repositories' level of safety.

2.1.1.5 Potential impact of the legal and regulatory framework on monitoring

Indications on how the legal and regulatory framework as well as the recommendations from the Safety Guide might translate into monitoring objectives were given in previous sections. A key item is re-emphasized here. The duration of the French pre-closure phase is on the order of a century. It is both due to (i) an estimate of the time needed to emplace the entire waste inventory and (ii) the legal requirement that the repository preserves the capacity for reversible management over at least 100 years.
This fairly long pre-closure time, combined with a possible need of monitoring in non-accessible areas (no maintenance, no recalibration or replacement of monitoring equipment), presents a significant challenge for available monitoring technology. This is seen as one of the central questions for monitoring R&D programme in France: The challenge for durability and reliability of monitoring equipment.
Specific consideration needs to be given to site hydrogeological monitoring: Although French water protection regulation forbids maintaining boreholes open and in operation for any length of time, it is envisioned that future permits for boreholes to be drilled in direct connection with repository construction (as opposed to current site investigation) will be associated with the duration of the installations, to be able to monitor the impact of repository construction and operation on site hydrogeology.

2.1.2 Expert stakeholders' expectations

Overall expert stakeholders expectations are expressed in the existing legal and regulatory framework, presented above. In addition, periodic reviews by the government appointed *Commission Nationale d'Evaluation* (National Evaluation Commission) have recently shown an increased interest in monitoring developments, and expect to be informed on technological R&D progress and on the overall approach (strategy) chosen to implement monitoring activities within the disposal process.
Overall, monitoring of the repository from the beginning of the construction and operation phase is expected to provide verification and/or a better understanding of anticipated behavior and evolutions of disposed waste canisters, engineered barriers and subsurface infrastructure, as well as of the host rock perturbations associated with repository construction and operation. This should contribute to the knowledge basis to undertake the decisional process as the repository process goes along. Clearly, the respect of any legal requirements must be shown and any monitoring in relation to operational safety carried out.
Associated expectations may thus be attributed to main objectives of:

- Confirmation of phenomenological models and parameters linked with the long-term safety assessment. When the coherence between in-situ measurements and results obtained from calculations are consistent over the first few decades of repository, confidence on long-term safety is strengthened.
- Reinforcement of models expertise. Knowledge on expected phenomenological evolutions of repository is described in details during the operating phase but also for long-term behavior. As specifications of installations are often based on conservative assumptions and as prior analyses take into account degraded and worst-case evolution scenarios, monitoring contributes to confirm the availability of margins.
- Support of the step-by-step repository process management: to provide supporting information allowing to pursue the reversible management of repository or to anticipate on decisions if some evolutions come close to expected uncertainty boundaries.

- Verification of operational safety and legal requirements conformity.

Prior to repository closure, above listed expectations can be translated into an overall approach for monitoring within the context of the French repository programme, which shows close similarities with Structural Health Monitoring (SHM), new field of research and development within civil engineering. The question of the extent and type of monitoring to be performed after closure is open.

Up to now, the most common method of evaluations of civil engineering structural health was based on regular visual inspections. SHM is developing because the complexity of new structures has significantly increased for the last 50 years (Millau Bridge in France, Rion-Antirion Bridge in Greece, Stonecutters Bridge in Hong Kong, Akashi Kaikyo Bridge in Japan, etc.). SHM is also implemented in old civil structures that need to face the challenge of increasing lifetime while maintaining the transportation network, thus limiting cost while minimizing perturbations for the users. The information obtained is used to plan and design maintenance activities, increase the safety, verify design basis, etc. The specificity of underground repository is that cells will not be accessible any more as soon as the first nuclear waste has been placed. SHM and more precisely sensor networks will be more than a tool supporting visual inspections. It will have to provide all information needed to state structural evolution in time.

Monitoring will start with construction and shall go on during the entire operation, until closure. In the context of a repository, acquired information from in-situ monitoring will include data on the structures and their environment. Monitoring to inform reversible management will focus on knowledge required to re-assess or confirm pre-closure evolutions of interest, while monitoring to confirm the models and parameters of interest for the long term safety case will focus on the scientific basis for long term safety evaluation.

The duration of the construction, operation and step wise closure period (time scale of a century) and the conditions in waste disposal drifts (no access) are challenging boundary conditions if one expects to monitor over such duration, in non-accessible areas. In addition to developing and implementing adapted technology, an overall monitoring strategy needs to be developed to respond to monitoring objectives.

2.1.3 Lay stakeholders' expectations

Identifying Lay stakeholders' expectations in general with regard to a repository, and more specifically with regard to monitoring, is not an easy task.

Various communication tools are organised in order to stimulate exchanges with lay stakeholders. Andra proposes many publications. For instance, until the end of 2009, a local newspaper published every trimester by Andra is dedicated to information on activities at the Meuse/Haute-Marne site. This has been replaced in 2010 by an agency wide newspaper informing on all research and industrial activities on all sites. Andra industrial sites (already existing nuclear storage sites as well as research underground laboratory) can be visited by lay stakeholders, students and scholars. Visitor centres are dedicated to public information. In 2006, more than 7000 people visited the LSMHM underground laboratory.

To assist its' efforts in consultation and information, Andras' Science Advisory Board (Conseil Scientifique) has advised Andra to create an Expert and Overview Committee for the information and consultation approach (Coesdic). It underlines the central position reversibility will take in future public debates and advises to undertake exploratory research on the various stakeholders' expectations.

The legal framework provides for various formalized interactions with the public at large. First, national public debates are held prior to major decisions being taken with regard to radioactive waste management. The 2006 public debate focused on the feasibility study for geological disposal (Dossier 2005) and preceded the parliamentary debate and vote on the 2006 Waste Act. Licence application for the creation of a waste repository in 2014 will be preceded by a public debate in 2013.

Second, the legal framework (French laws dated Dec. 30th 1991 and June 28th 2006) states the existence of a *Comité Local d'Information et de suivi* (CLIS, French acronym for Local committee for information and surveillance). It has to collect information, to follow Andra's research and developments, ensure consultation and debate with lay stakeholders. It was created in Nov. 1999 in Bar-le-Duc near the LSMHM. It is currently composed of 91 representatives from the two French administrative regions and departments where the repository is likely to be implanted, with various, complementary backgrounds (politicians, environmental associations...). It publishes its own website (http://clis-bure.com/).

Although questions addressed to Andra are in constant evolution, two main subjects tend to focus the attention and thus provide some indication for lay stakeholder's expectations: reversibility and the localisation of a future repository.

The meaning of "reversibility" has been subject of numerous exchanges. For instance, questions addressed to Andra during summer 2009 were:

- What is the volume of waste, for each of the waste categories potentially intended to be stored in the deep repository?
- Is the repository designed to be irreversible in the end, with a period of at least 100 years during which retrievability will be possible? (and if yes, when will this period start?)
- Or else, are transmutation perspectives taken into account to envisage a possible new way of management?
- When will the packages be impacted by the galleries narrowing? Will the galleries be backfilled, and if yes, what will be the impact on galleries' and packages' evolution?
- The types of conditioning as a function of used materials: which life time? What resistance to crushing? What would be the consequences of damages on a package due to crushing?
- Is a cooling of waste packages expected while inside the disposal drifts? If yes, what kind and with what consequences?
- How far has research on monitoring systems progressed?
- Do current research/studies aim to create a post-closure memory as long as possible, or would "forgetting the site" be a preferred approach to guarantee the site's safety, by reducing the risk for future attempts to enter/harm the site?

The localisation of future surface and underground installations of the repository is of major interest and has recently attracted significant attention. Criteria to be taken into account were discussed prior to developing a formal approach for a more precise siting within the 250 km2 transposition zone under investigation.

Among the expectations expressed after the 2006 public debate, the final report issued by the Public Debate Commission indicated in particular that "the exchanges have to continue […], so as to share the possibilities offered by reversibility and to make this concept more tangible and accessible to the public". It also highlighted a view that social sciences approaches are pertinent and should accompany the development of the underground repository project.

In this respect, Andra decided to make a progressive engagement of the Social Sciences community and focused particularly, in a first approach, on researches related to the notion of reversibility. A specific section devoted to social sciences research and studies was introduced in the scientific program of the Agency according to this orientation in 2008.

As far as the reversibility issue is concerned, the integration of Social Sciences approaches aims at exploring the various components of this notion and the elaboration of Andra's rationale. Therefore, this integration will allow Andra to incorporate the social aspects into the conception of the future repository and to enhance exchange with stakeholders.

Several actions have been initiated so far in this respect. Since this academic year, Andra propose grants for the realization of PhD thesis in Social Sciences and support complementary research in the hosting departments. The main objective, for Andra, is to sustain the creation of a specialized research community strongly mobilized around the reversibility question. A PhD in economics is currently financed by Andra.

Scientific meetings have also been programmed. A first meeting on reversibility took place last October. This meeting consisted in a one-day workshop with 8 presentations prepared by Andra's representatives, each highlighting a specific field of study and its' relation to reversibility and each discussed by a Social Scientist. Other researchers from the Social Sciences were also invited at the general discussions (around 30 participants in total). Andra should adapt its work to the exercise, which represented a sort of test. The meeting aimed also at calling up the interest of the Social Sciences community and at bringing on the development of new initiatives.

Furthermore, the workshop made important contributions in terms of structuring Andra's research and future discussions. First of all, it called attention on the need of clarification of terms and arguments. The fact that reversibility goes beyond the possibility to retrieve the waste packages was particularly stressed: reversibility has to do principally with the decisional processes and in particular with the possibility to come back on the former decisions. In other words, reversibility is supposed to enlarge the spectrum of available choices and give guidance to their use.

A strong tendency to present reversibility, paradoxically, as an ineluctable way that leads to irreversibility was also signaled. In so doing, the positive aspects of reversibility are often let aside or neglected. Even if Andra's stepwise approach (and the associated process of decision by recurrence) was highly appreciated, a Social Scientists analysis introduced the notion of "cognitive irreversibilities", which may remain and could go against the technical reversibility. Changes in the way of thinking about reversibility seem also necessary. In this sense, one of the meeting conclusions was that a work to define the diversity of options and scenarios has to be developed in relation to the public debate.

The importance of creating tools in support of Andra's exploration was also pointed out and some of the social scientists participating in the meeting accepted to work in this direction. A study concerning the argumentative forms of reversibility in a socio-historical perspective is currently in progress. Similarly, the gradually setting of a documentary space devoted to reversibility, to work on in participative bases, is at study.

Based upon this workshop's outcomes, an interdisciplinary conference on reversibility was organized in Nancy, the 17th-19th June 2009. Among the questions received, the technical ability to conduct monitoring over the fairly long phase prior to closure was addressed. The question was raised whether the loss of such monitoring capacity might invalidate the ability of reversible management.

Later on, the French approach of reversible repositories will be consolidated in the international conference that will be organized under the auspices of OECD/NEA in 2010.

Overall, there appears to be an increasing interest towards monitoring. At this stage, it appears to focus on general questions, such as pertaining to longevity and reliability of monitoring systems. The debate also appears to be closely tied to reversibility. More specific monitoring expectations by lay stakeholders are not yet clearly identified. As regards to public health and safety, it appears that a key concern is the verification of (current?) conditions guaranteeing their protection. This might be translated in the verification that no radioactive pollution in the environment is detected and linked to the repository (residual pollutions e.g. from the Tchernobyl accident can still be detected in the environment, without however presenting any threat to public health). With regard to long term safety evaluation, a specific link to monitoring does not appear to have been made.

2.2 Physical Aspects

2.2.1 Waste inventory and properties

The inventory includes all ILLL (intermediate level, long lived) radioactive waste, HL (high level – vitrified) waste and the fraction of spent fuel for which retreatment does not present sufficient interest (for instance all naval spent fuel). A thorough description of the waste inventory considered and associated waste properties can be found in (Andra 2009a).

This inventory includes approximately 110.000 m3 of ILLLW primary waste packages, which include:

- Waste from structure and technology origin, conditioned in *Conteneurs standards de déchets compactés* (CSD-C, Standard compacted waste canisters);
- Waste from bituminized treatment of effluents;
- Activated and technological waste conditioned in concrete containers;
- Nuclear reactor dismantling waste;

There is also an estimated 12.000 m^3 of HLW primary waste packages, an order of magnitude less in volume that the ILLLW, which includes:

- Vitrified waste characterized by a moderated production of heat (less than 10% of the HLW inventory)
- Vitrified waste characterized by a higher production of heat (for which disposal can only begin after several decades of cool-down storage)

In addition, a comparatively small volume of spent fuel resulting from research and defence activities is currently foreseen for disposal in the repository. Its properties allow to consider mixed disposal together with moderate heat-producing HLW.

Minimum duration of emplacement operations is estimated several decades for the ILLLW and the HLW. Combined with a prior cool-down period for the higher heat producing HLW (current thermal management decisions and design require up to 70 years of cool-down between vitrified waste production and disposal) leads to an overall estimate of emplacement operation duration on the order of one century. Such duration is a key technical element to take into account for the design of monitoring systems and for the selection or development of adequate technology.

Certain of the ILLL waste forms produce hydrogen, which calls for the need of gas build-up monitoring. Certain primary waste packages may release small amounts of radioactive gas, which calls for the monitoring need associated with such radioactive gas and adequate design and monitoring for the entire ventilation system.

Although heat generation of HLW and residual heat generation of some of the ILLLW are taken into account during architecture and disposal drift design, the heat signature of disposed waste is an important monitoring objective, as it may allow drawing conclusions on:

- Decrease of waste form activity,
- Engineered barrier characteristics and evolution,
- Near field evolution (especially pertaining to level of saturation, through the functional relation between saturation and thermal conductivity)
- Overall host rock properties (drift scale and repository scale thermal conductivity, compared to laboratory determined thermal conductivity).

2.2.2 Host rock

The French HL and ILLL radioactive waste programme investigates a Clay Stone layer over a transposition zone of 250 km2, located in the East of France. The centre of this very homogeneous layer is at about 500 m depth and its thickness is larger than 130 m (between 130m and 160m). Its properties were thoroughly described e.g. in (Andra, 2005).

The absence of fractures in the investigated zone and the overall very low permeability (diffusion dominated transport, absence of preferential flow paths) and favourable geochemistry (reducing environment, low solubility of radionuclides, strong sorption of all but a few radionuclides to the host rock) are important elements in the safety case. Any activities (excavation: excavation damaged zone) or evolutions (desaturation-resaturation, heating, chemical interaction with concrete or steel, hydrogen production…) that may have an impact on this must be well understood and taken into account.

The water transport properties of the host rock (diffusion controlled flux rates) limit near field desaturation during operation in ventilated access tunnels and disposal drifts. They also limit resaturation after drifts and tunnels have been closed. This has implications on the mechanical properties (coupled hydro-mechanical rock deformation).

Due to the very low permeability of the host formation, the only expected interaction with overlaying formations during the pre-closure phase is related to access shafts and access ramps. Any impact on surrounding aquifers due to excavation and operation will need to be monitored to respect water environment protection regulations. This interaction will be controlled after closure through emplacement of backfills and seals, and predicted migration paths of radionuclides several hundreds of thousands of years after closure are exclusively by diffusion through the host rock.

The lateral homogeneity of the host formation associated to each layer may be used, among other things, to justify that the evolution of any given underground structure is representative of the evolutions of similar structures. Therefore, monitoring of any given representative structure should also provide reasonable insight of the evolution of similar structures, provided construction protocols and used materials are identical or sufficiently similar.

The mechanical properties of this host rock call for the design and emplacement of adequate ground support, to ensure operational safety during construction and operations, in particular to ensure controlled operations of waste canister handling during waste emplacement and in the event of waste retrieval. The associated monitoring objectives in the repository focus on the mechanical evolution of the ground support and of the near field, to anticipate stress increases and deformations.

2.2.3 Engineered barriers

An overview of engineered barriers and structural components concepts considered by Andra is provided in (Andra, 2009b).

2.2.3.1 Waste Disposal Package

The waste form is conditioned into primary waste packages. The primary waste packages will be repackaged into disposal overpacks. One steel overpack each is foreseen for the vitrified waste and "CU3" spent fuel primary packages. Regrouping of several primary packages into a concrete overpack is foreseen for the ILLLW. Waste disposal packages have a mechanical function, related to the capacity to emplace and potentially retrieve waste, and to maintain geometrical form of the primary waste package and waste form. The vitrified waste disposal packages also have a water tightness function, to prevent any water getting in contact with the waste form during the thermal period, defined as the period required to achieve post-emplacement cool down below 50 °C (on the order of a thousand years for certain categories of vitrified waste).

Ease of retrieval relies on waste package integrity (retrieval operations of a damaged package might lead to substantial technical complications), as well as on the conditions in the disposal cell (quality of ground support, cell environmental conditions).

2.2.3.2 Structural components and disposal cell liners

Prior to backfill and closure, the basic structural elements used within the repository are either large diameter, concrete lined and ventilated structures or small diameter, horizontal, steel lined, non ventilated structures.

The large diameter structure group includes ramps, shafts, connecting and access drifts as well as IL waste disposal cells. These structures have a concrete liner and are all ventilated as long as they remain opened. Diameters are on the order of 10m.

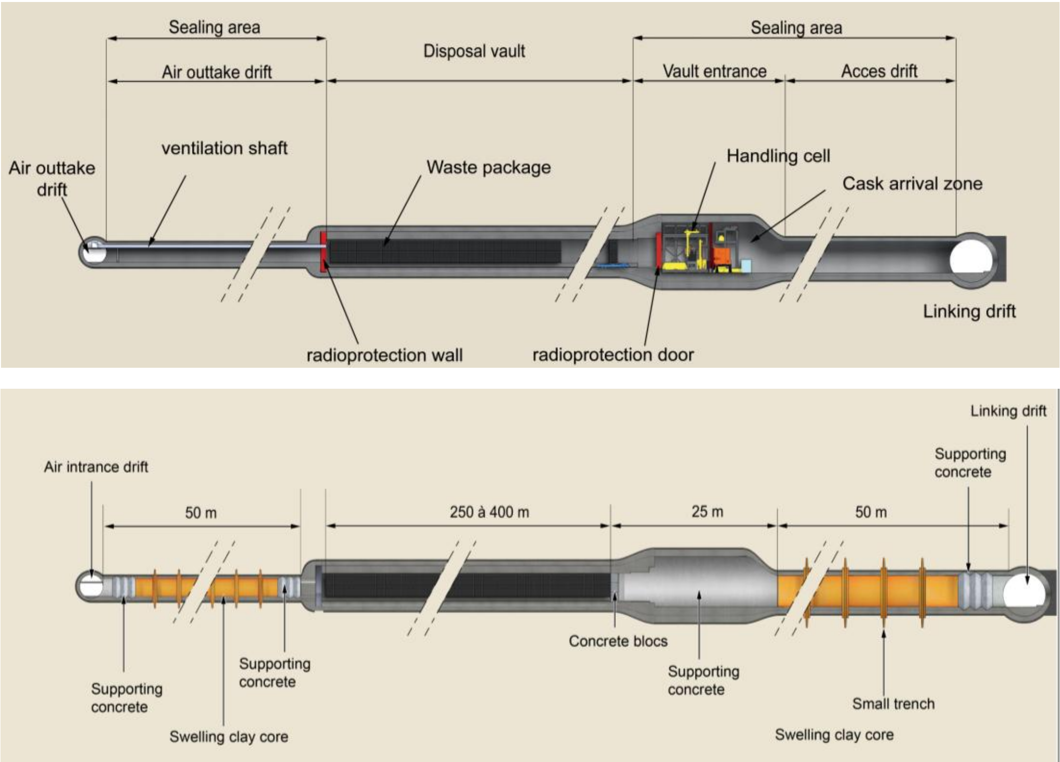


Figure 2-1: IL waste cells concept – Configuration during operations (top) and after sealing (bottom)

Among these elements, only the disposal cells will contain nuclear waste, the others are the repositories construction, operation, and closure infrastructure. The ILW disposal cells are illustrated in Figure 2-1 above, both for their configuration allowing waste package handling (top) and for the sealed configuration (bottom). The structural components respond to requirements allowing for emplacement and potential retrieval of the waste disposal package. After closure, the concrete surrounding the primary waste packages will buffer the water chemistry eventually reaching the radioactive waste.

The small diameter structure group includes all HL waste disposal cells. These horizontal cells won't be ventilated. A cylindrical envelope of non-alloy steel provides mechanical stability. Their inner diameters will on the order of 70cm. These disposal cells are illustrated in Figure 2-2 below. This structural component responds to requirements allowing for emplacement and potential retrieval of the waste disposal package. Its long term resistance to corrosion – at a minimum during the century scale operational phase – is ensured by design and by placing the liner in a low-corrosion environment. The latter is achieved by preventing air exchange with the access galleries, thus providing for an anoxic environment. These anoxic conditions also substantially limit the corrosion rates of the waste disposal packages.

Corrosion rates are an important indicator for the expected liner and package performances. Corrosion monitoring could be carried out indirectly and could emphasize verification of favourable, i.e. anoxic environmental conditions, which control the corrosion rates.

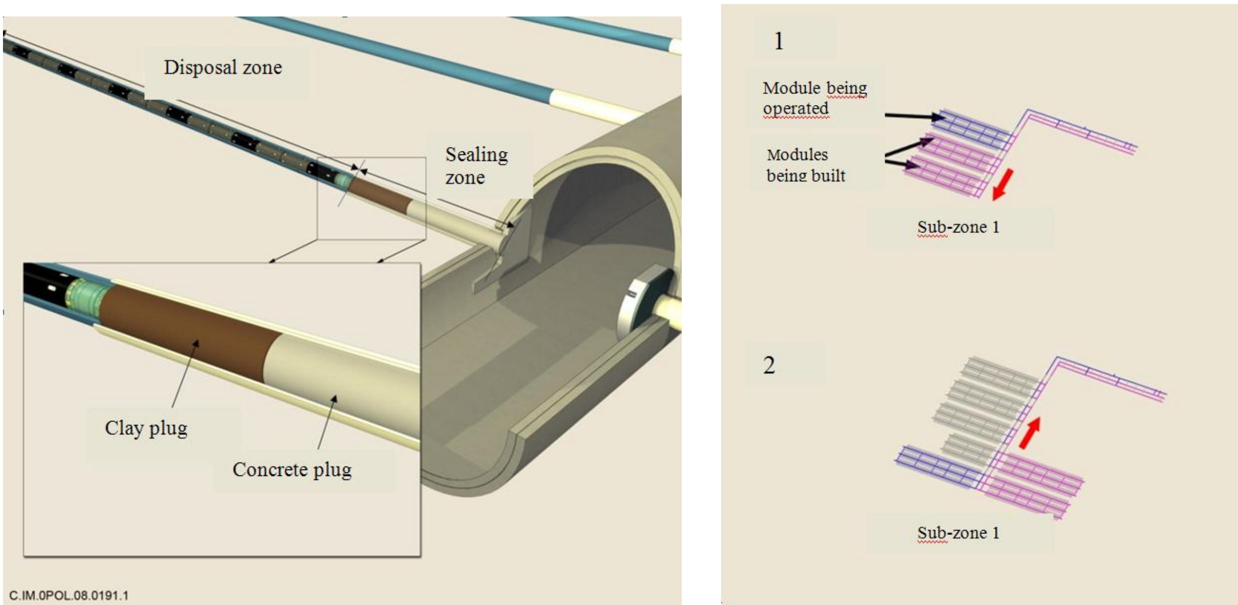


Figure 2-2: HL waste cells concept and the progressive development of the HLW zone.

2.2.3.3 Backfill and seals

In addition to these basic structural elements introduced in the previous section, various closure elements are used for repository backfilling and sealing. These are mostly made of clay material (swelling clay or clay stones), with the exception of concrete plugs providing mechanical support for seals. Specific closure backfills and seals are foreseen at the head of each IL and HL waste cell, and for the entire infrastructure (drifts, shafts and ramps).

Access tunnel backfill has a mechanical function, to minimize long term host rock deformation (and potential associated degradation of transport properties) by minimizing residual void volume. To achieve this, adequate compaction of the backfill is required. Corresponding monitoring objectives can be developed, although their potential to provide useful results needs to be analyzed first (as long as ground support remains in place, recompaction of backfill due to host rock deformation is not likely to happen until after ground support failure and then is likely to be subjected to time scales far beyond what may be monitored).

Access tunnel and shaft seals have a hydraulic function: Prevent/Reduce water circulation from disposal cells to access shafts or ramps to acceptable levels. Given the time scale for natural resaturation of swelling clay seals, corresponding monitoring objectives must be developed to contribute to the lines of evidence that seals will work, without having to monitor the seal in its long term (resaturated, buildup of swelling clay pressure, sealing of hydraulic pathways) configuration.

2.2.4 Disposal concept – repository layout and progressive implementation

Two key aspects govern the current view on managing the disposal process in France. One is the reversible approach (Andra 2009c), whose principle is prescribed by law, over a period which cannot be less than 100 years, but for which technical details must be developed by Andra (cf. description above). A law expected in 2016, after submission of a license application, will specify requirements related to reversible management.

The other aspect is related to the size of the inventory, which also argues in favor of spreading out construction activities in time, to provide disposal space when needed. This leads to having concurrent activities of excavation and repository construction, emplacement of waste disposal packages, and progressive closure of disposal drifts.

These considerations lead to the development of a repository layout based on repository components respecting the following requirements:

- Modularity enabling construction in successive phases and flexible management of each repository module;
- Durable repository structures (access drifts, disposal cells, waste disposal canisters);
- Identification of successive stages for closure that can be decided with flexibility in time;
- Design options facilitating potential WDP retrieval (rock support, minimization of residual gaps around WDPs, no need for disposal cell backfilling after waste emplacement, etc.);
- Monitoring provisions to support ongoing management of the repository and the waste (representative structures monitored through the successive closure stages).

The overall repository layout is structured into disposal cells, disposal modules, and disposal zones. Disposal cells are specifically designed either to received ILW, or HLW disposal packages, as introduced above. Disposal modules regroup a sizable fraction of the overall waste inventory: Several hundred HL waste disposal cells are regrouped in a single HL waste disposal module, as illustrated in Figure 2-2. The more sizable IL waste disposal cells are each considered as a specific module. All modules of a same waste category are regrouped into a disposal zone: The ILLLW disposal zone and the HLW disposal zone.

Disposal cells, modules and zones are separated from each other in a way to limit possible interactions between them that may be detrimental to their expected performance.

Heat generation of HLW and residual heat generation of some of the ILLLW are taken into account during architecture and disposal drift design, and include a prior cool-down period for HLW in interim storage and an in-situ cool-down period through ventilation for ILLLW. The French repository design ensures that peak temperatures will not exceed 100°C anywhere (the hot spot being on the HLW disposal package) and will not exceed 70°C in a few of the ILLLW drifts, and only in the event of ventilation failure (most will always remain significantly cooler, close to ambient).

As a consequence, thermal environmental conditions for a monitoring system are mostly benign, except inside HLW disposal drifts. Temperature resistance of monitoring equipment must be provided for, for example for systems that are to be attached to the cell liner (metal sleeve).

2.2.5 Progressive closure or "one-pass" closure

Andra clearly imposes a gradual staged closure, incorporated into a progressive decision-making process. An immediate technological consequence of such gradual closure is the gradual complication of retrievability as one moves towards an increasingly passive configuration. Such gradual closure can be structured in a series of steps, as presented in Figure 2-3. The corresponding relative ease of retrievability is presented in Table 2-1, along with specific elements of active control and of passive safety present at each step. These are currently being developed within the NEA Reversibility and Retrievability project (OECD/NEA 2010), and are reproduced here to illustrate the progressive approach envisioned by Andra.

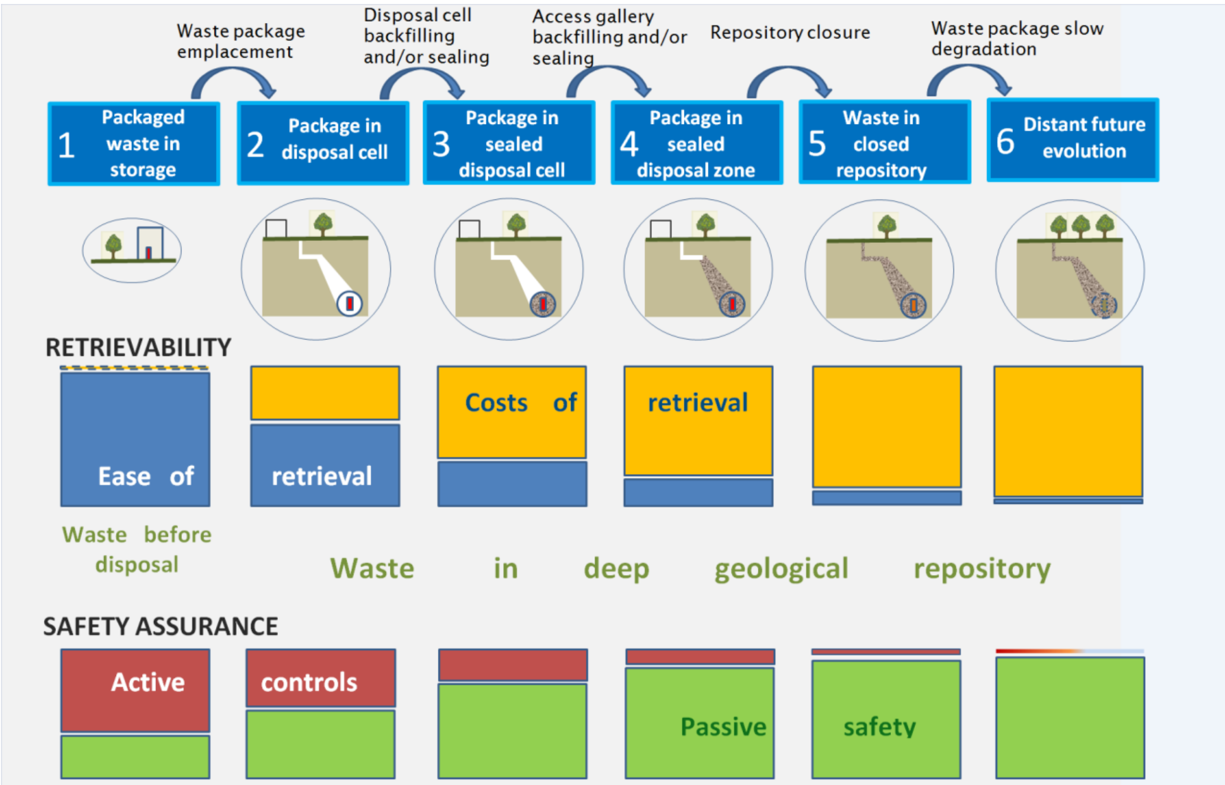


Figure 2-3 The NEA R&R project graphic presentation of the R-scale

During the steps of the disposal process, the scale is based on the increasing effort needed for retrieval, which is related to progressive implementation of passive management components and decreasing need of active management. Level 0 is the level of raw waste, not conditioned, which requires intensive surveillance. At level 1, waste is conditioned in a package, and stored in an interim surface storage facility. At level 2, waste is disposed in a deep underground disposal cell. Several hundreds of meters of rock provide a passive protection. The emplacement cell has still to be monitored. At level 3, the emplacement cell is sealed. Access galleries to the cell have still to be monitored and maintained, e.g. ventilated. At level 4, the access galleries are backfilled and sealed. The disposal zone is closed, and eventually the entire disposal facility is closed. At this stage, no monitoring or maintenance of the disposal zone (or facility) is necessary, but remote monitoring may be still performed for some duration of time commensurate with institutional site surveillance. Waste remains contained within the waste disposal packages. At level 5, which takes place a long time after closure, the integrity of the disposal packages may no longer be guaranteed, but waste is still confined within the engineered facility. A significant part of short-lived radionuclides have disappeared. This stage is similar to a mine having a high uranium ore concentration. No maintenance or monitoring is required. But markers may be erected to remind future generations that radioactive wastes are disposed of deep underneath.

Table 2-1 Waste lifecycle stages, ease of retrieval, and specific elements of passive safety and active control as developed in the NEA R&R project.

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

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

2.2.6 Possible implications for monitoring

The progressivity of construction and operation also has implications on monitoring, as indicated in Table 2-1 above. The French disposal process will conduct construction, operation and partial closure in parallel. The first investment to be made is surface to depth infrastructure and access tunnels to the first ILLLW disposal drifts. Such infrastructure, which must remain operational for the full duration of the disposal process, will be monitored for mechanical stability, to ensure sufficient remaining life time and/or to recommend needed maintenance. The first ILLLW disposal drifts are to be monitored in response to all technical monitoring objectives that will have been identified. Instrumentation that is incorporated into the host rock and the drift liner needs to be included in the design and emplaced during construction.

Subsequent ILLLW disposal drifts can be instrumented and monitored based on remaining requirements – i.e. if monitoring of the first disposal drifts provides needed confidence, it may be decided to limit instrumentation of later construction. Conversely, any subsequent decisions based on technical or stakeholder input may also be taken into account to increase monitoring ambition.

The progressive approach and the long duration, combined with probable lessons learnt from the first few disposal drifts, will likely lead to an evolution in disposal drift design. This type of option is explicitly identified as one of the technical aspects of reversible management of the disposal process. For example, design evolutions may include the use of improved materials not available at time of first construction. Any such evolution will be accompanied by an analysis of potentially evolving monitoring needs.

Monitoring is easiest while a structure is accessible, i.e. in open access tunnels and in disposal drifts that have not yet received waste packages. It is constrained by lack of accessibility in irradiated disposal drifts (after waste emplacement). Certain monitoring strategies may provide adequate answers, for example combining non-accessible, non-maintainable in-situ sensors with mobile and maintainable measuring devices.

The progressive approach also imposes technical difficulties on the overall monitoring network. It calls for the need of an evolving network (ability to connect and disconnect branches), over a time frame that is long compared to monitoring technology “half-life” (need to store equipment compatible with initial monitoring technology; need to integrate new technology that is compatible with prior equipment; need to update part of the measurement chain – transmission, acquisition, data management – without losing continuity of qualified data…).

2.3 Decisional process

In the French programme, the decision to site a repository in a specific area, based on prior investigations and feasibility studies was taken after the evaluation of the 2005 feasibility report (Andra 2005), and the site for ongoing further detailed investigations is constrained to a 200 km2 zone in the East of France. The 2006 Law on radioactive waste management calls for the submission of a license application by 2014. This same Law stipulates that only a parliamentary decision can authorize the ultimate closure of the repository.

Between these major decision points on initiating construction and on ultimate closure, additional decision points can be defined to structure the management of the disposal process. In France, these decisions are taken as part of the reversible management of the disposal process. This was introduced and illustrated above with a series of progressive closure steps. While the original disposal plan provides for such a progressive closure, decision points must also offer the opportunity to redirect the disposal process – e.g. delay sealing of a given disposal cell, update the design of future cells... – and in particular provide for the option of retrieving waste canisters.

Monitoring plays a role in informing on the status of subsurface structures, their evolution as well as the evolution of their environmental conditions, to help assess available management options for the disposal process. This is not the only source of information input, as societal or political input or changes in the overall management of the fuel cycle may call for certain adjustments in disposal process management. Here only such technical, in situ information that may be obtained through monitoring is considered. Arguably the most extreme decision that could be made is retrieving waste after it has been disposed of. Monitoring should provide information pertaining to the feasibility of such retrieval and to the ease or technical difficulty of such retrieval. Information should also allow preparing any remedial action that may be called for before retrieval is possible.

More generally, to provide reversible management with reasonable flexibility, monitoring should provide information on the remaining time frame allowing safe operations in any part of the repository. This provides indication if all possible options are still open at the next decision point. Otherwise, and to prevent any future urgency imposed on the decisional process, monitoring should indicate whether action is needed (maintenance, closure, or waste retrieval) to preserve reasonable flexibility in management options.

It is expected that the modalities of these decision points and of reversible management in general will be further defined in a Law on Reversibility, which is called for by 2016.

2.4 References

Loi n° 91-1381 du 30 décembre 1991 relative aux recherches sur la gestion des déchets radioactifs

Loi n° 2006-686 du 13 juin 2006 relative à la transparence et à la sécurité en matière nucléaire

Loi de programme n° 2006-739 du 28 juin 2006 relative à la gestion durable des matières et déchets radioactifs

Autorité de sûreté nucléaire (2008) Guide de sûreté relatif au stockage définitif des déchets radioactifs en formation géologique profonde

Andra (2005) Synthesis Argile – Evaluation of the feasibility of a geological repository in an argillaceous formation

Andra (2009a) Référentiel de connaissances et modèle d'inventaire des colis de déchets à haute activité et à moyenne activité à vie longue. Andra report n° C.NT.AHVL.09.0114.

Andra (2009b) Options de conception du stockage en formation géologique profonde. Andra report n° C.NSY.ASTE.08.0429.

Andra (2009c) Options de réversibilité du stockage en formation géologique profonde. Andra report n° C.NT.AHVL.09.0005.

Andra (2010a) Observation-surveillance des ouvrages du stockage en formation géologique profonde. Andra report n° C.RP.AHVL.08.0083.

Andra (2010b) Options de sûreté du stockage en formation géologique profonde. Andra report n° C.NT.ASSN.09.0029.

OECD (2010, draft) Reversibility and Retrievability (R&R) for the Deep Disposal of High-Level Radioactive Waste and Spent Fuel – Intermediate Findings and Discussion Documents of the NEA R&R Project (NEA/RWM/PROV)

3. German National Context (DBE TEC)

3.1 Societal Aspects

3.1.1 Expert stakeholders' expectations

The strategy and thus all monitoring activities are based on the defined reasons for monitoring. Monitoring starts with the characterization of conditions at the undisturbed site (baseline conditions) and lasts during repository construction, operation, closure and institutional control. After closure, the long-term safety of geological disposal facilities, due to the duration of the hazard associated with the waste cannot rely on institutional controls, including monitoring. A prognosis whether future generations are able to cope with the problem of radioactive waste and/or are willing to take on the responsibility is impossible and due to the principle of inter-generation equity not permitted anyway. Therefore, experts think that final disposal has to be effected in such a way that an intrinsic and passive safety is ensured and that a final repository does not require post-closure monitoring.

However, continuing monitoring is likely to be a societal demand for some time after repository closure. Experts think that monitoring may strengthen the confidence of society in final disposal, but no one has ever checked this out.

Monitoring activities that rely on intrusive methods are to be avoided. At the time being the expert opinion is that post-closure monitoring in Germany may contain radiological monitoring of the environment as well as the monitoring of vertical movements of the surface. The latter could be satellite-based and could thus contribute to safeguard aspects, too.

With regard to the definition of monitoring, all processes and parameters important to safety shall be addressed. This includes the safety for all mining operations and for the waste disposal activities. The German safety criteria require applying state-of-the-art technologies. Prior to any equipment installation an approval from the BfS has to be achieved (see chapter 2.1.3 Legal Framework). Monitoring systems shall be transparent to inspections. That means the measurement system should be as easy as possible with regard to system structure, handling and documentation. At present, a data base system to keep monitoring data (all kind of monitoring data) is used at DBE. This is to provide all the information to people who have to work with these data at DBE, BfS and BGR (if required) and for proof keeping reasons. These data are used to evaluate the operational safety and can provide input data for predictive calculations of the system evolution.
With regard to monitoring the following instructions and guidelines are established by experts and to be considered:

- The applicability of monitoring systems shall be independent of the geological environment. Any adaptation shall only be a question of specification, housing, etc.
- All systems to be applied shall be based on the state-of-the-art technology.
- Where ever possible a sufficient redundancy of measurement systems shall be implemented.
- Measurement frequency depends on how the individual process can be representatively recorded taking data handling efficiency into consideration.
- Raw data and processed data shall be independently recorded.
- Result evaluation shall consider local effects as well as regional system evolution.
- A regular reporting to the authorities („Jour-fixe“) is to be performed.

- A catalogue on fault reporting shall continuously be updated (distinction between mining law and atomic law).

3.1.2 Lay stakeholders' expectations

Remark: "The following text is not directly related to expectations on monitoring but deals with trust and confidence. It represents the main outcome of a meeting with local stakeholders.

Stocktaking from Meeting with Local Stakeholders from Gorleben (HLW) and Konrad (L/ILW) Areas (OECD/NEA, 2004):

This session aimed at meeting local actors and learning about their concerns regarding trust, confidence and fairness in decision making for radioactive waste management in Germany. Five statements were made by representatives of local stakeholders from the Gorleben and Konrad areas. Based on these statements, the session Chair and Co-chair helped identifying the major questions to be taken out for further discussion with the audience.

Ulrich Flöter, a farmer from Gartow, who has been involved in community policy for about 25 years, spoke of his experience regarding decisions on the Gorleben site. He pointed out that Gorleben was suggested for mining and resources reasons, and that, in the debates, party politics has received more weight than science. The community would be willing to accept the facility if science showed that it is safe, **but local support can only be achieved through involving the local public**. Unfortunately, the local community has not been actively involved in the AkEnd workshops (AkEnd, 2002). Presumably, the Stage 2 public debates will not take place either, which is very regrettable.
Mr. Flöter judged that 2030 is not a realistic date for a disposal facility to be operational. He suggested that Gorleben should be included in site investigations and be compared to other potential sites.

Ursula Schönberger representing "AG Schacht Konrad" recalled that the Konrad mine was proposed by the local community as a disposal facility. It was put forward as the regulator had given its view on its safety. It was originally planned for medical waste, hut it has been expanded to hosting utility wastes as well: nowadays, only about 2% of the Konrad-designated waste would originate from hospitals and universities. The initiative against Konrad started already in 1979. The local Opposition group took the proposals to court, but in order to do this, they had to raise a significant amount of money. Over the years, the Konrad site has become a political toy, whereby attitudes change with changing politicians.
Ms. Schönberger judged that AkEnd was a positive development, but she also expressed her concerns that many of AkEnd's recommendations will not be transferred to legislation. Finally, she warned that nothing should be done under time pressure.

Andreas Graf Bernstorff, a landowner from Gartow emphasised that Gorleben was not chosen in an open and transparent way and politics played a key role. He had refused selling his land for a reprocessing facility, and he did not sell his mining rights either. He lost trust in the process because Gorleben was chosen in spite of the fact that the geological conditions are insufficient: the channel that exists in the Gorleben salt dome calls safety into question.
Mr. Bernstorff said he supports AkEnd, and agrees that the site should be reconsidered in light of the new criteria. He also recognised that a radioactive waste management facility has to be established and decisions have to be made now. However, he expressed doubt whether the new law can achieve what it is aiming for.

Francis Althoff of “Bürgerinitiative Umweltschutz” (citizens’ initiative for environmental protection) confirmed that in past decisions, as well as in recent debates, politics has been more important than science, and science seems to be overpowered by “power“. He judged that although large sums of money have been spent already, this does not justify pursuing Gorleben. He spoke about recent conflicts; even transporting the waste from France to Gorleben every November is very difficult and needs a large police presence.
Mr. Althoff expressed his support for a new siting process and the search for an alternative repository site. He emphasised that the public needs to be involved in the new process.

Eckhard Kruse, a church pastor from Gartow explained the main reasons for the public losing trust in the institutions and actors. He spoke of the **lack of dialogue with the public**, the mismatch between the words and the actions of the authorities, and the misuse of power during waste transports. He also claimed that radioactive waste management institutions have no trust in the citizens.
Mr. Kruse suggested that a new approach should be found, **whereby the responsible authorities trust citizens and involve them in their decisions**. He pointed out the importance of transparency, clear site selection criteria and dialogue, and emphasised that the AkEnd proposals are promising. In addition, AkEnd has opened an important discussion on ethics. Finally, Mr. Kruse suggested that waste transport to Gorleben should be stopped.

Discussion
Based the above presentations, Anna Vári, Professor, Hungarian Academy of Sciences (session Chair) and Peter Hocke-Bergler from Karlsruhe Research Centre (session Co-chair) identified the following questions to be discussed with the audience:
- Should the sites selected earlier (Konrad and Gorleben) be kept among the alternatives to be investigated?
- How should geologic, economic, social, and political criteria be balanced?
- What should be the roles of the different actors, particularly of governments, authorities, experts, utilities, and the (local and broader) public? How should responsibilities be shared?
- How should transparency and an open dialogue be maintained? How to resolve the conflict between the need for a time-consuming public participation (e.g., exploring the decision criteria with the public) and the time pressure (radioactive waste management is the responsibility of the current generation)?
- What should be implemented? Nothing? The proposal of AkEnd? A compromise?
- Which political way of solution? Take a break? Find a solution? Do stakeholders want to go a new way?

The main outcomes of the discussion were summarised by the Chair and Co-Chair as follows:
- Local confidence in actors responsible for previous site selection processes has seriously been shaken in affected areas. The evaluation of the AkEnd approach is more or less positive, but this new attempt of site selection will take place in a context of negative earlier experience.
- Authorities and political actors have been strongly criticised for their top-down approach, which is unsuitable for conflict management. **They are asked to be more open to local interests**.
- Stakeholders express their wish for finding a safe site and would welcome a comparative approach. However, this could be problematic in the presence of the Gorleben moratorium.
- The role of expertise needs to be considered and the quality of expertise needs to be improved. The possible role of “counter-experts“ is a controversial issue.

- The main reason for losing trust and confidence was that earlier decision making was not seen as being fair. There is a need to rebuild confidence while trying to find a solution.
- A process that is seen as being fair by stakeholders and affected public needs to be developed. A key factor of fairness and confidence is the management of the existing conflicts. AkEnd is seen as a good starting point for developing such an appropriate process.

References:

AkEnd, 2002: Site selection procedure for repository sites, recommendations of the AkEnd (Committee on a site selection procedure for repository sites), Final Report, 248 pages, Cologne, Germany.

OECD/NEA 2004: Disposal of radioactive waste: forming a new approach in Germany, FSC Workshop Proceedings, Hitzacker and Hamburg, Germany, 5-8 October 2004.

3.1.3 Legal and regulatory framework

3.1.3.1 Relevant Laws, Ordinances, and Regulations

In Germany, laws and ordinances do not specifically deal with HLW or LILW disposal, but with disposal of radioactive waste in general. The basis of the German regulatory framework is the:

3.1.3.1.1 Fundamental Law for the Federal Republic of Germany (Grundgesetz für die Bundesrepublik Deutschland).

The Fundamental Law, which entered into force in 1949, is the constitution of the country. Pursuant to this Fundamental Law Germany has a federal organization, with the Federal States being given strong competencies in all aspects of public life. In principle, the Federal States have all competencies not explicitly assigned to the Federal Government. Art. 74 of the Fundamental Law, in its section 11a, assigns to the Federal Government the jurisdiction to regulate:
“The generation and use of nuclear power for peaceful purposes, the construction and operation of facilities to this purpose, the protection against the hazards associated with these activities or with ionizing radiation as well as the disposal of radioactive waste”.
This assignment of jurisdiction to regulate radioactive waste disposal has a direct influence onto the distribution of roles and responsibilities between the different authorities and parties working in the field of licensing a repository for radioactive waste.

The Regulatory framework ruling Radwaste in the Federal Republic of Germany includes the following laws and ordinances:

3.1.3.1.2 Atomic Energy Act.

Law on the Peaceful Use of Nuclear Energy and the Protection Against its Dangers, (Gesetz über die friedliche Verwendung der Kernenergie und den Schutz gegen ihre Gefahren – Atomgesetz, AtG) of December 23, 1959, last amended on July, 2002.

The Atomic Energy Act rules only general aspects of the licensing procedure and the licensing requirements for a LILW repository. It contains no technical or scientific regulations concerning the design, location, construction, operation, closure, and monitoring of a final repository for radioactive waste.

3.1.3.1.3 Law on the Establishment of a Federal Office for Radiation Protection

(Gesetz über die Errichtung eines Bundesamtes für Strahlenschutz) of October 9, 1989, last amended on May 3, 2000.

The Law on the Establishment of a Federal Office for Radiation Protection defines BfS's duties. With this law all tasks related to safekeeping of fissile Materials, supervision and licensing of radioactive materials transportation, and disposal of radioactive waste including disposal site development, which until then had been entrusted to PTB, were transferred to BfS.

3.1.3.1.4 Ordinance on the Protection Against Damage by Ionizing Radiation

Radiation Protection Ordinance (Verordnung über den Schutz vor Schäden durch ionisierende Strahlen – Strahlenschutzverordnung StrlSchV) of October 13, 1976, last amended on July, 2001.
The Radiation Protection Ordinance rules all aspects of protection against damage caused by ionizing radiation. It is fully applicable, <u>without exception</u>, to the operation of a radwaste repository. It contains no special regulations for repositories.

3.1.3.1.5 Federal Mining Act (Bundesberggesetz, BBergG) of August 13, 1980, last amended on August 21, 2002.

The Federal Mining Act is applicable to the establishment of repositories for final disposal in Germany because this act not only rules the mining of natural resources but also the construction and operation of underground facilities for storage of goods and disposal of waste. In addition to the mentioned laws and ordinances, the responsible authority for regulating radioactive waste management and disposal, at that time the Federal Minister for Internal Affairs, published in 1983 the

3.1.3.1.6 Safety Criteria for the Final Disposal of Radioactive Waste in a Mine (Sicherheitskriterien für die Endlagerung radioaktiver Abfälle in einem Bergwerk) of January 5, 1983.

This is the main rule dealing with siting, construction, operation, and closure of a repository for geological disposal of radwaste. As previously stated, the Federal Government, represented by the then competent Federal Ministry for Internal Affairs, promulgated the "Safety Criteria for the Final Disposal of Radioactive Waste in a Mine" in a memorandum of April 20, 1983, to the licensing and regulatory authorities directing them to take the Safety Criteria into consideration in future licensing procedures. Whenever the licensing authorities of the Federal States do not interpret the Safety Criteria as intended by the Federal Government, the Federal Government can force compliancy by issuing directives. The safety criteria are in the process of being revised to be adapted to the most recent state of the art.

Geological final disposal of radioactive wastes is defined by these criteria as maintenance-free, temporally unlimited, and safe isolation of such wastes from the human environment, without a-priori intention of retrieval. The criteria are rather generic, in order to provide a flexible framework that can be adapted to different site conditions.

Although this set of criteria was published in 1983, i.e. after selecting the sites Konrad and Gorleben, it formalizes in a generic manner all aspects actually considered in the site selection processes. Moreover, it also sets up guidelines for the further steps of site development and later repository construction and operation. The Safety Criteria qualitatively specify measures to be taken to achieve the protection objective of disposal, and define the principles by which to demonstrate compliance with the objectives. The basic idea is that safety is ensured by a series of technical measures and by methods and/or procedures adjusted to one another. The importance of the site selection and the use of state-of-the-art technology are emphasized.

Recent changes of safety requirements in Germany: extraction relevant to monitoring

In July 2009, BMU, the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, issued the Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste. BfS, the Federal Office for Radiation Protection, shall apply these safety requirements to a future final repository for heat-generating radioactive waste in Germany. All other repositories shall continue to be governed by the Safety Criteria for the Final Disposal of Radioactive Waste in Mines published in 1983 in the Bundesanzeiger (Federal Gazette).

Up to now, there have not been any regulations in Germany for the monitoring of deep geological repositories after repository closure. (The Safety Criteria published in 1983 includes the assumption that closed mines do not require any maintenance or monitoring at all.) The Criteria stipulate radiochemical monitoring of the air and of water bodies close to the surface in addition to geodetic levelling of the surface.

In accordance with international developments, an increased need to collect and record data in a repository after closure is now recognised in Germany as well. In this context, the new Safety Requirements of BMU stipulate in chapter 7.4 that:

"A monitoring and evidence preservation programme must be used during emplacement operations, decommissioning, and for a limited period following decommissioning, in order to verify that the input data, assumptions and statements of the safety analyses and safety cases performed for this phase have been observed. In particular, this measurement programme should record the impacts of the rock's thermo-mechanical reactions on the heat generating waste, technical measures and rock-mechanical operations. Measurements should continue to include the initial status and development of activity concentration in spring water and groundwater, soil, water bodies and the air within the repository's sphere of influence. Any significant deviations from such data, statements and assumptions in the cited safety cases should be evaluated with regard to their safety relevance. If necessary, counteractive measures should be carried out by the operator during emplacement or decommissioning in order to avoid any impairment to important safety functions. Where approval is needed for such counteractive measures, this should be obtained by applying to the competent authority. The competent authority shall also decide who will perform the measurement programme following decommissioning, and when this measurement programme may be discontinued."
A full version of the new German Safety Requirements Governing the Final Disposal of Heat-Generating Radioactive Waste can be found on
http://www.bmu.de/files/pdfs/allgemein/application/pdf/endfassung_sicherheitsanforderungen_en.pdf

The need for long-term monitoring is of particular importance for the former research mine Asse-II if the waste already disposed of in the mine is to remain there after its closure.

So far, the federal government does not have a comprehensive set of criteria that can be used as a basis for assessing which safety-relevant data on the state of a repository mine can be collected in the early post-closure phase. (It is presumed that all data that can be obtained from a closed repository mine will have to be collected in a more comprehensive manner and in higher quality during the operational phase as well.)

3.1.3.1.7 Regulatory Authorities in Respect to L/ILW Disposal and their Advisory Organizations

Germany is a country with a Federal structure. This has a strong influence on the structure of the regulatory, licensing, and supervisory bodies in the field of nuclear waste management and disposal. The Fundamental Law assigns the competence for nuclear matters, and hence for radioactive waste management, to the Federal sphere. The German Parliament, in turn, assigned in 1976 by the fourth amendment of the Atomic Energy Act the responsibility for providing installations for radioactive waste final disposal to the Federal Government.
Pursuant to § 23 of the Atomic Energy Act, BfS, which is a body of the federal administration directly subordinated to BMU, is responsible for construction and operation of final repositories. It is the applicant for a license on behalf of the Federal Government, and legally responsible for the repository operation and its supervision in regard to nuclear matters. This supervision begins after the end of the licensing procedure. The legal supervision monitors the construction, operation and decommissioning of the repository in accordance with the regulatory content of the operational license.

Under exclusive contract with BfS, DBE
(i) carries out the repository planning, including preparation of the license application and of the supporting body of documents,
(ii) constructs and operates the repository,
(iii) performs the site survey and the complete repository monitoring.

Based on the described legal framework the following regulations and guidelines have to be considered with regard to repository monitoring:

Atomic energy act
Federal Mining Act (BBergG)
Federal Emission Protection Act
Act for the order of water regime
Mining Ordinance for Health Protection (GesBergV)
Ordinance for Mine Ventilation (KlimaBergV)
General Ordinance for the storage of dangerous waste
Radiation Protection Ordinance (StrlSchV)
Safety criteria for the final disposal of radioactive waste in a mine
Guidelines for shaft backfilling and monitoring
Guideline for Emission and Immission Monitoring at Nuclear Facilities (REI), Part C2: Repositories for Nuclear Waste, 12-20-1995.
DIN 25423: Sampling for Monitoring of Radioactivity in Air, Dec. 1999.
KTA Safety Rule 1503.1: "Monitoring of the Release of Gaseous and Aerosol Bound Radioactive Substances, Part 1: Monitoring of Radioactive Substances Releases via the Stack During Normal Operation", Issue 6/93.
KTA Safety Rule 1503.2: "Monitoring of the Release of Gaseous and Aerosol Bound Radioactive Substances, Part 2: Monitoring of Radioactive Substances Releases via the Stack During Normal Operation", Issue 6/93.
KTA Safety Rule 1504: "Monitoring of the Release of Radioactive Substances with Water", Issue 6/94.Text

3.2 Physical Aspects

3.2.1 Host rock

The preferred host rock is rock salt. Its characteristics can be summarized as follows:

Thermal Characteristics

The main parameters characterizing the thermal behaviour of a salt host rock are the thermal conductivity, the specific heat capacity and the density. For the Gorleben site the following constitutive laws and parameters were used:

- Thermal conductivity — $\lambda(T) = a1+a2 \cdot T+a3 \cdot T^2+a4 \cdot T^4$
  With
  T = Temperature
  $a1 = 1.3196 \cdot 10^1$ W m^{-1} K^{-1}
  $a2 = -3.7384 \cdot 10^{-2}$ W m^{-1} K^{-2}
  $a3 = 4.0974 \cdot 10^{-5}$ W m^{-1} K^{-3}
  $a4 = -1.51 \cdot 10^{-8}$ W m^{-1} K^{-4}

- Specific heat capacity — $c_p(T) = b1+b2 \cdot T$
  With
  $b1 = 8.0254 \cdot 10^2$ J kg^{-1} K^{-1}
  $b2 = 1.7624 \cdot 10^{-1}$ J kg^{-1} K^{-2}

- Density — $\rho = 2200$ kg m^{-3}

Hydraulic Characteristics

The main parameters characterizing the hydraulic behaviour of the host rock salt are the permeability and the effective porosity.

- In situ measurements of permeability in rock salt yield values of $k = 10^{-21}$ m^2 (hydraulic conductivity = 10-^{14} m^2 s^{-1}) and lower.
- With regard to effective porosity, no fixed values were specified for rock salt. For indicative calculations values in the range 0.01% to 0.1% were used.

Other parameters like relative permeability and capillary pressure were not yet determined. With these very low values rock salt can be seen from a technical point of view as very tight.

Mechanical Characteristics

Salt is a viscoplastic material that shows strongly time-dependent deformation behaviour under mechanical load. Furthermore, the rate of such deformation is markedly dependent from the rock temperature. Under laboratory test conditions e.g., under a constant load, all three creep phases can be observed: the primary creep, characterized by a decreasing creep rate; the secondary or stationary creep, with a constant creep rate; and the tertiary creep, with increasing creep rate leading to total failure of the rock probe.

To model the behaviour of salt rock under in situ conditions, a constitutive law has proven to be appropriate consisting of an elastic deformation model and a secondary creep part. This law is implemented with an additive split into an elastic part, described by Hooke's law and a viscoplastic term. The material parameters of the elastic part are: elasticity modulus E = 25 GPa and Poisson ratio $\nu = 0.27$. The viscoplastic part follows the Norton power law to model the stress dependency and an Arrhenius-function to consider the temperature influence on the creep rate as follows:

$$\dot{\varepsilon}_{ij}^{vpl} = \frac{3}{2} A e^{-\frac{Q}{RT}} \left(\frac{\bar{\sigma}}{\hat{\sigma}} \right)^n \frac{S_{ij}}{\bar{\sigma}}$$

where:

n	: stress exponent n = 5
A	: material parameter A = 0.18 d-1
Q	: activation energy Q = 54 kJ mol-1 K-1
R	: universal gas constant R = 8.314 J mol-1 K-1
Sij	: components of stress deviator
T	: absolute temperature
	: components of viscoplastic strain rate
	: von Mises equivalent stress
	: normalizing stress = 1 MPaText

3.2.2 Waste inventory and properties

The nuclear power plants considered would generate a total of 24,030 MTHM (metric tons of heavy metal) until the year 2040, when the last reactor is taken out of operation. Out of this, 19,128 MTHM of spent fuel will be directly disposed of.

Vitrified radioactive waste will be disposed of in standard canisters referred to as COGEMA-Canisters (see Figure 3-2). The burn up is assumed to be for all of the fuel 33,000 MWd/THM. The reference fuel is a UO2 PWR fuel assembly with a Uranium enrichment of 4 % and 50,000 MWd/THM average burn up. The waste package is a Pollux-8-Cask (Figure 3), filled with the disassembled rods of 8 fuel elements. It was originally planned to fill the cask’s central bin with compacted fuel assembly structural parts. In a concept update it was later decided to load the central bin with the fuel rods of two additional fuel elements, and to dispose of the compacted fuel element structural parts in so-called CSD-C containers (colis standard de déchets compactés). As an alternative spent fuel can be put in a spent fuel cask called BSK-3 that is three times the hight of a HLW cask but with the same diameter. Thus the handling for disposal of the BSK-3 in vertical boreholes is similar to the HLW-cask. Figure 3-1 shows the casks together with their heat power.

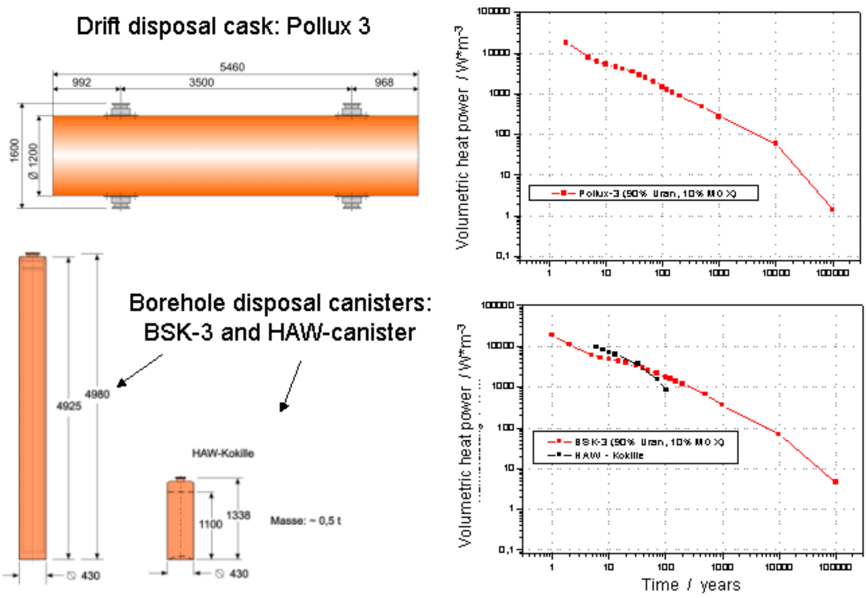


Figure 3-1: Waste canisters and heat power

3.2.3 Engineered barriers

The German reference disposal concept considers crushed rock salt as the engineered barrier around the disposal canisters. Engineered barriers for drift and shaft sealing are currently under development

3.2.4 Progressive closure or "one-pass" closure

In Germany reference disposal concepts have been developed for rock salt and claystone being the host rock. In any case the underground facilities are structured in several emplacement fields (or disposal cells). Due to the co-activity of excavation, disposal operation and backfilling and sealing of individual disposal cells the process can be seen as a progressive closure.

3.2.5 Disposal concept – architecture

Operations in a repository will consist of the following steps in the case of borehole disposal of vitrified HLW, BSK-3 and CSD-Cs. Waste packages will be delivered to the site by railway or truck in a shielding overpack that contains one waste package. After incoming inspection the overpacks will be loaded onto the facility-internal rail bound transport carts by bridge crane. Thereafter, the transport cart will be positioned for hoisting in front of the hoisting cage safety gate. When the hoisting cage is in place, the safety gate will open up and the transport cart will be pushed into the cage by means of an under-floor caging device. The cage will then be hoisted down to the emplacement level.

A battery-driven mining locomotive will haul the loaded transport cart from the mine station through the access drift to the disposal field until reaching the predetermined position in the disposal drift. Thereafter, the shielding overpack will be lifted from the transport cart by the emplacement device for borehole disposal (Figure 9) and locked to the borehole shielding plug. After interlocking checks both the lock of the shielding overpack and of the borehole plug will be opened and the canister lowered down into the borehole.

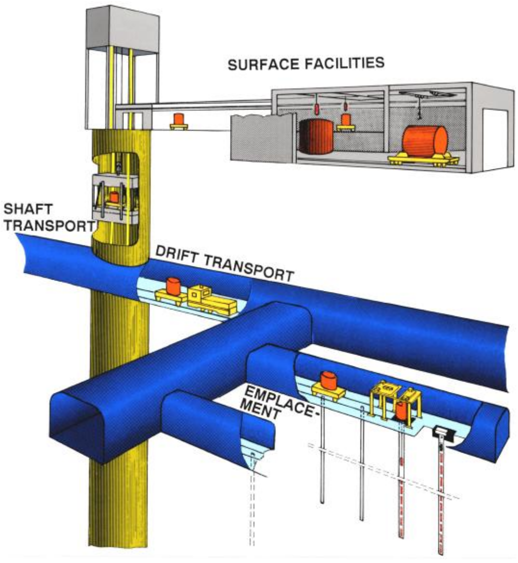


Figure 3-2: Borehole Disposal - Sequence of Operations

3.3 Considerations and potential implications related to monitoring

3.3.1 The impact of host rock

The German concept still relies on rock salt being the host rock.

Deformation measurements are essential due to occupational safety. A monitoring programme has been established at the Gorleben and Morsleben sites to observe the plastic behaviour of the salt. The programme focuses mainly on the deformation of underground cavities, fissure opening and closure as well as on water inflow (if any). Monitoring results are evaluated regularly and discussed by experts. Based on these evaluations potential measures are discussed and applied in order to prevent for any danger.

3.3.2 The impact of local and regional hydrogeology

At the Gorleben and Morsleben sites a hydrological monitoring programme has been established. It focuses on the observation of groundwater level, salinity and radionuclide detection. In any case the programmes are quite similar depending slightly on the amount of ground water layers and local groundwater regime.

3.3.3 The impact of overall repository architecture

The underground disposal area will be subdivided into several emplacement fields. Monitoring in one emplacement field will only take place during the period this field is under operation. Monitoring equipment will be dismantled during the closure of this field.

3.3.4 The role of waste disposal package for operational and/or long term safety

Due to occupational safety radiological monitoring will be performed covering waste acceptance, waste package handling and transport. In principle this is not dependent on the kind of waste package (Pollux cask or HLW-cask).

3.3.5 The impact of cavern, drift or borehole disposal of waste packages

Generally, the German concept does not include monitoring close to waste canisters. Monitoring is therefore just related to the rock behaviour of the individual emplacement field as well as fluid management (harmful gases and brine). Thus, monitoring for drift or borehole disposal is similar.

3.3.6 The role of gallery and shaft seals for long term safety

Due to experiences concerning shaft and drift sealing obtained from corresponding re-search projects / in-situ tests, the correct installation of a sealing construction to ensure the proper work of the sealing is a very difficult task. Thus, to prove the proper work of the construction by monitoring without reducing the isolation function is a critical issue. In the framework of recent approval procedures (2009) the following statement has been made:

“In case the tightness of a barrier is endangered, all monitoring equipment has to be removed and all cables have to be cut and sealed”

Moreover, it seems to be impossible to prove the long-term stability of cable material. Material degradation might lead to fluid pathways along the cabling. Currently it is very unlikely that any cable based monitoring equipment will be installed within a barrier system in a repository for HLW in Germany.

4. Spanish National Context (ENRESA)

4.1 Societal Aspects

4.1.1 Expert stakeholders' expectations

The Spanish regulatory authority has until now not established specific requirements (e.g.. pilot facility, etc) to drive monitoring needs and approaches.

4.1.2 Lay stakeholders' expectations

Currently, there is no interaction of lay stakeholders with the geological disposal program. This interaction is expected in future (more advanced) phases of the program.

4.1.3 Legal and regulatory framework

Regulatory requirements related to monitoring are associated with operational safety in terms of radiological protection to individuals (ICRP and IAEA standards apply as for any other nuclear facility). On the other hand, the mining regulations apply, as for any other underground facility, to ensure the operational safety during the construction phase, in terms of preventing geotechnical and environmental problems (dust, gas concentrations, temperature, etc).

There are until now no specific regulatory requirements linked to the reversible management of the waste disposal process in the repository.

Monitoring during the post closure phase is restricted to monitoring of environmental radiation and continuation of some monitoring activities initiated during the site characterization phase (seismicity, groundwater levels, precipitation, etc). Related to long term safety, the dose to individuals of the critical group is set below 1mSv/year.

Spanish Regulations

Legislation:
Among the most important legislation with implications for monitoring:

- Nuclear Energy Act (Law 25/1964)
- "Real Decreto 783/2001 Reglamento sobre Protección Sanitaria contra Radiaciones Ionizantes": Royal Decree which incorporates Council Directive 96/29/EURATOM, 13 May 1996. Laying down basic safety standards for the health protection of the workers and the general public, against the effects of ionising radiation.
- "Real Decreto 1836/1999 Reglamento sobre instalaciones nucleares y radiactivas": Royal Decree with regulations about nuclear and radioactive installations and licensing procedures.

Regulatory Guides (Spanish Nuclear Safety Council):
The regulatory authority (Nuclear Safety Council) issues Regulatory Safety Guides for specific purposes related to nuclear installations. Some of them deal with monitoring aspects, but not specifically related to waste disposal facilities:

- GSG 01.04 Radiological control and surveillance of liquid and gaseous radioactive effluents arising from NPPs.
- GSG 04.01 Design and development of an Environmental Radiological Surveillance Programme for NPPs.
- GSG 05.03 Control of encapsulated radioactive sources

Technical Instructions (from Spanish Law of Mines)

- ITC 04.7.02 Limit values for gas concentrations, temperature, humidity and climate conditions.
- ITC 04.7.04 Ventilation: inspection and surveillance
- ITC 04.8.01 Environmental conditions: dust.

4.2 Physical Aspects

4.2.1 Waste inventory and properties

Waste and spent fuel inventory

The inventory includes spent fuel elements from NPPs, very small amounts of HLW (vitrified) and ILW (no heat generation). Assuming a 40 years lifetime of the existing NPPs the related volumes are as follows:

- 14.400 spent fuel elements (equivalent volume ≈ 10.000 m3)
- 84 HLW COGEMA packages (volume ≈ 13 m3)
- 12.500 ILW units (volume ≈ 5.000 m3)

The waste emplacement operation time according to current repository design and planning is 41 years (7 years repository construction, 30 years operation and 4 years for repository closure).

4.2.2 Host rock

Crystalline rock and sedimentary (plastic clay) rocks have been considered during a site selection program conducted by Enresa in the past decade. Several areas have been identified and retained for future characterisation studies.

The current legal and regulatory requirements provide just a very general framework for monitoring during the construction and operational phase (chapter 3.1), in accordance to the "early phase" of development of the Spanish program (i.e. no safety assessment has yet been conducted and presented to the safety authority).

4.2.3 Local and regional hydrogeology

The impact of the repository construction and operation in the local an regional hydrogeology will be monitored to, on one hand, confirm existing understanding and knowledge on hydro mechanical coupled processes, and on the other hand, to ensure compliance with water environmental regulations.

The response of the host rock to the repository will be studied in a URL close to the facility, by means of a comprehensive long-term experimental program on the relevant processes (thermal, mechanical, hydraulic and geochemical). This will be confirmed during the construction and operational phase.

4.2.4 Waste disposal package (WDP)

The WDP in the Spanish concept is a cylindrical carbon steel package, 0,9 m in diameter and 4,54 m in length, about 15 tons in weight, with a minimum life expectancy of 1000 years (containment period). During the operational phase, for handling and transport purposes, the WDP is repackaged into one steel overpack with 15 cm neutronic shield. There are no provisions to monitor the WDPs when emplaced in the disposal area of the repository.

4.2.5 Role of the gallery and shaft seals

The repository design contemplates the emplacement of seals made of unsaturated compacted bentonite blocks at different locations throughout the facility (disposal and access galleries, shafts and ramp), to prevent any potential preferential migration path linked to these repository elements. The seal performance at full saturation is to be confirmed, given the time scales involved, at the URL facility by conducting specific experiments involving forced artificial resaturation.

4.2.6 Other Engineered barriers

The repository design contemplates the WDP surrounded by unsaturated compacted (1,8 g/cm3) bentonite blocks. The role of this bentonite barrier is to limit the flow towards the WDP and to provide significant retardation to the radionuclide migration to the host rock, once the WDP fails due to corrosion. The bentonite evolution and performance during resaturation and at full saturation is to be confirmed, given the time scales involved, at the URL facility by conducting specific experiments involving forced artificial resaturation.

5. Belgian national context (Euridice)

5.1 Societal aspects

5.1.1 Expert stakeholders' expectations

The Belgian "expert" stakeholders are:

- the government regulator: FANC (Federal Agency for Nuclear Control);
- the regional authorities (e.g. Flemish) – non-radiological aspects;
- the waste management organisation (WMO) NIRAS/ONDRAF;
- the waste producers: Belgian State (historic waste), Synatom acting for the NPP;
- the nuclear research organisation SCK•CEN;
- academic world (Belgian and international).

In addition, as international "expert" stakelholders we can list: IAEA, NEA, and Euratom.

The expectations might be summarised as "safe" and "feasible": a safe waste management involving the temporary storage (including e.g. non-proliferation), operation of a disposal facility and the long-term protection of people and environment; a feasible waste management both technically and economically.

5.1.2 Lay stakeholders' expectations

For these expectations, first experiences have been gained through the local partnership groups dealing with the category A waste disposal project. These groups have been established in 2000 to create a local social basis by drafting a project (one for each partnership group) for the disposal of this waste together with the WMO; each project was proposed to the government, who took a final decision in 2006.

Regarding the category B & C waste, a first consultation has been performed by NIRAS/ONDRAF in the frame of the preparation of an Environmental Effects Report (*EER*). Details of this consultation process are given in the next part dealing with the legal and regulatory framework.

5.1.3 Legal and regulatory framework

The following regulations have to be applied (non exhaustive list):

- The Belgian Regulations **ARAB/RGPT** for general rules on safety at work;
- the general the general regulations relating to measures in the field of the health and safety of workers in **mines**, underground quarries and galleries, and with the Royal Decree of November 4, 1996 amending the Royal Decree of January 10, 1979, relating to prevention policy and the bodies responsible for health, safety the and the improvement of workplaces in mines, excavations and underground quarries;
- the protection from **ionising radiation** as described in the Royal Decree of 20 July 2001 (to be further analysed) for the Public and the Workers. The Royal Decree of April 25, 1997 relates specifically to the protection of employees from the risks of ionising radiation (Belgian Statute book of July 12, 1997);
- the General Regulations on Electrical Installations (**RGIE/AREI**), and regulations on the use of electricity in mines, excavations and underground (Royal Decree of September 20, 1990 amending the Royal Decree of September 5, 1969),

Belgium is subjected to the IAEA Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

FANC did not issue yet formal, specific regulations or guidelines on the management of the category B and C waste.

The Belgian Government appointed NIRAS/ONDRAF in 2004 to evaluate various options for the long-term management of the category B and C waste.

The "Law of 13 February 2006 concerning the *Evaluation of the Consequences for the Environment of certain Plans and Programmes and the Involvement of the Public for the Elaboration of the Plans and Programmes concerning the Environment*" requires that strategic decisions with an important impact on the environment shall be based on an in-depth evaluation of different options. This evaluation process is obligatory. In order to comply with this Law, NIRAS/ONDRAF has planned to draw up the "Waste Plan". The overall purpose of the Waste Plan is to establish a future strategy concerning the long-term management of category B and C waste. The environmental effects reporting is a process during which consequences on the environment are analysed and assessed in a comprehensive and systematic manner. This assessment can be performed at two levels, in particular the level of plans and programmes and the level of projects. The result of this evaluation is a Environmental Effects Report (*EER*). Depending on the level of the plans, distinction can be made between two types of EER. A EER at the level of plans and programmes is called a *Plan-EER*. While a plan-EER will include an assessment at a broad level, a *project-EER* will contain more detailed information since the purpose of the project-EER is to evaluate the effect of technical and site-specific aspects of the project on the environment.

The Law of 13 February 2006

The Law of 13 February 2006 has been created in order to convert the following European Directives into National Law: Directive 2001/EG issued by the European Parliament and the Council of 27 June 2001 concerning the evaluation of the consequences for the environment of certain plans and programmes and Directive 2003/35/EG EG issued by the European Parliament and the Council on 26 May 2003 concerning the involvement of the public in the drafting of certain plans and programmes. The Belgian Law of 13 February 2006 foresees the following main steps:
(1) The applicant shall, in view of the drafting of a (Plan) Environmental Effects Report (EER), draw up a draft register with information to be included in the (Plan)-EER. This draft register defines the scope and the level of detail that will be included in the Plan-Environmental Effects Report (Plan-EER).
(2) The draft registry shall be submitted to an Advisory Committee. The Advisory Committee assesses the draft registry within a period of 30 days after receipt.
(3) The applicant is required to draft a Plan-EER, taking account of the draft registry and the advice given by the Advisory Committee.
(4) The applicant shall submit the Plan-EER as well as the original version of the draft registry for advice to the Advisory Committee, the Federal Counsel for Sustainable Development, the Regional Government and all other parties considered appropriate. The Law foresees that, at the same time, a public consultation process shall take place. This public consultation process shall be announced in the Official Gazette, on the portal site of the Federal Government, and through at least one other communication medium. A 60 days period is foreseen for this step.

(5) The applicant shall then convert the draft Plan-EER into a EER that is to be submitted to the competent authority. Upon acceptance of the Plan-EER by the competent Authority, a declaration shall be drafted summarising the way how environmental considerations were integrated in the Plan-EER and identifying how account was taken of advices and remarks.
(6) The approved plan-EER and the explanation are then published in the Official Gazette and published on the Federal Portal site.

General implementation scheme

The concept of the Plan-EER is comparable to the "Strategic Environmental Assessment" (SEA) which is a terminology that is more broadly used in an international context. The main purpose of the Plan-EER is to ensure that all environmental considerations are taken into account in the decision-making process, prior to approval of the plan or programme and prior to the implementation of the projects following these plans or programmes. allows NIRAS/ONDRAF has planned to analyse in the Waste Plan all possible options regarding the long-term management of category B and C waste. However, these options will not be discussed at the same level of detail. The plan-EER forms part of the NIRAS/ONDRAF waste plan and will include all elements required to allow the Belgian Federal Government to take an 'in principle' decision concerning the longterm management of category B and C waste.

The NIRAS/ONDRAF Waste Plan

In the framework of the Law of 13 February 2006, NIRAS/ONDRAF has planned drafting two reports, in particular the Waste Plan and the plan-EER, which forms part of the Waste Plan. The Law foresees that the EER and the Waste Plan are submitted to public consultation. The time frame specified by the law (60 days) is however not suited to discuss in public a complex matter such as waste disposal. NIRAS/ONDRAF has therefore set up a broad consultation process and societal dialogue.

The public consultation process and societal dialogue

In the period March-May 2009, NIRAS/ONDRAF has organized a broad societal dialogue in order:

- to assess whether the social basis for the necessity of the taking of a decision in principle itself;
- to identify the values and the concerns that have to be taken into account for the decision in principle;
- to complete the list of factors that have to be taken into account in both the plan-EER and the Waste Plan considering different possible management options.

The social dialogue and consultation process focuses on three groups:

- the public at large;
- members of representative organisations;
- experts in various competence areas who are familiar with the decision-making process in complex environmental and societal decisions.

Implementation programme

NIRAS/ONDRAF prepared the public consultation process in three major phases:

(1) all preparatory activities are undertaken that will lead to the drafting of all supporting documents for the participative consultations that are planned in phase 2;
(2) participative consultation of the public at large, scientists and experts;
(3) all steps required for the establishing of the assessment and participation procedure as imposed by the Law of 13 February 2006 will be prepared and executed.

Main communication instruments and scheduling

NIRAS/ONDRAF has established different communication channels to interact with each of the interest groups:

- a dedicated website has been established (http://www.nirasafvalplan.be/). It will be used as the main communication channel with the public at large. From the website, documents can be downloaded, and questions and comments/feedback can be submitted.
- from 18 April to 16 May 2009, NIRAS/ONDRAF has organised eight "dialogues" with the public to find out the different aspects that the public is concerned about regarding the long-term management of highly active and long-lived radwaste. The results will help NIRAS/ONDRAF to establish the Waste Plan.
- on 30 April 2009, NIRAS/ONDRAF has organised an "Interdisciplinary Conference" bringing together experts from different scientific disciplines and industries. During this conference, experts that are familiar with the evaluation of long-term environmental effects and with decision-making in a context with various uncertainties discussed in four groups with a different approach: (1) scientific and technical dimension, (2) financial-economic, (3) safety and environment, and (4) society and ethics.

In addition, NIRAS/ONDRAF asked the King Baudouin Foundation – an independent and pluralistic foundation that pursues sustainable ways to bring about justice, democracy and respect for diversity – to organise a participative process by means of a public forum. Facilitated by reference persons and coaches, a diverse group of Belgian citizens will discuss during three weekends on the long-term management of radwaste in Belgium. A final report with conclusions and recommendations will be written during the last weekend. It will be handed over to the policy makers in February 2010.

Dissemination of the results from the public consultation process

The results of the social dialogue are communicated through the website mentioned. The social dialogue will concentrate on four major thematic areas:

- values and concerns to be taken into account in the framework of the decision in principle;
- identification of the required and sufficient basis needed to take a decision in principle;
- mechanisms to take into account intergenerational equity in comparing different options en decision-making;
- identification whether the decision in principle should a solution requiring either active or passive management.

Next steps/future plans

NIRAS/ONDRAF plans to submit the Waste Plan including the plan-EER to the Federal Government by mid 2010. By then, all elements will be available to the Federal Government to:

- take a decision on the management option for the long-term management of category B and C waste;
- to establish the decision-making process required to execute the chosen management option;

- to establish the means that have to be deployed in order to establish social support for the stepwise implementation of the chosen management option.

5.2 Physical aspects

5.2.1 Host rock

The Belgian R&D on the geological disposal of intermediate and high-level long-lived radioactive waste was initiated by SCK •CEN in 1974 and was soon directed to the Boom Clay beneath the Mol-Dessel nuclear zone following the final report of the Evaluation Commission for Nuclear Energy (March 1976) which concluded that, for Belgium, the deep argillaceous layers appeared to offer the best solution for the final disposal of this waste. At the Mol-Dessel nuclear zone, this formation is about 100 m thick, with its top at a depth of about 180 m below surface (or 155 m below sea-level).

Fifteen years later, the SAFIR Evaluation Commission (1990) concluded that the decision to study the Boom Clay at the Mol-Dessel nuclear zone was justified, but that it might also be worthwhile to consider other locations, e.g. the Doel nuclear zone, with its underlying Ypresian Clays. N/O embarked upon a research programme into these clays at Doel in the early 1990s.

The current situation, N/O regards:

- the Boom Clay as the reference host formation for examining a solution for the deep disposal of category B and C waste;
- the Mol-Dessel nuclear zone as the reference site for the methodological studies related to Boom Clay;
- the Ypresian Clays as an alternative host formation for researching and assessing a deep disposal solution in Belgium;
- the Doel nuclear zone as an alternative site for the methodological studies related to the Ypresian Clays.

Boom Clay host formation

In Belgium, the Boom Clay is present in the northeast of Belgium. The Boom Clay (or Boom Formation) belongs to the Rupelian (geological part of the Tertiary Period lasting from 36 to 30 My ago).

From the Boom Clay outcrops, the formation displays a 1 to 2 % dip towards the northeast and thickens in this direction. Its base is more than 400 m deep in the north of the Province of Antwerpen, but is more than 1000 m deep at certain places in the Roermond Graben, as a result of fault activity. In the Mol-Dessel region, the Boom Clay ranges from 190 to 290 m depth.

The Boom Clay is a silty clay – or argillaceous silt – with a high pyrite and glauconite content in its siltiest bands. One of its most remarkable characteristics is precisely this structure of bands that are several tens of cm thick, reflecting mainly cyclical variations in grain size (silt and clay content) Marly, grey-white, bands occur troughout the thickness of the formation. In these bands, the typical concretions ("septarias") are found. This band structure is visible in the clay pits (outcrops) and through borehole reconnaissance drillings, and show the remarkable lateral continuity of this clay.

Composition

The analyses on the mineralogical composition shows a wide variation in the content of clay minerals (30 to 70 %, with an average of 55 %), which reflects the vertical lithological heterogeneity of the Boom Clay. These clay minerals are complemented by quartz, feldspars, carbonates, and pyrite. Finally, some organic matter is present.

Table 5-1: Mineral composition of the Boom Clay

Clay minerals	30 - 70 %
Illite	
Smectite	
Chlorite	
Illite/smectite mixed layer	
Chlorite/smectite mixed layer	
Kaolinite	
Quartz	20 - 60 %
Feldspars	5-10 %
Carbonates	1-5 %
Pyrite	1-5 %
Organic matter	1-5 %

The total porosity of the Boom Clay, and hence its total water content, is some 30 to 40 % by volume. Water content and clay content are correlated.

Other properties

The sediment (banded) structure is also noticeable in many other characteristics, where a horizontal and vertical value is given.

Hydrological conductivity K (m/s):	6.10^{-12} (horizontal) - 3.10^{-12} (vertical)
Thermal conductivity λ (W/mK):	1.68 (horizontal) – 1.30 (vertical)
Thermal capacity $\rho.Cp$ (J/m³K) :	$2.90.10^{6}$

Mechanical characteristics (undrained)

Young's modulus E (MPa)	200 – 400 (tangential, at the origin)
Poisson coefficient ν	0.4 – 0.45
Friction angle ϕ	4°
Cohesion c (MPa)	0.5 - 1

Geophysical borehole logging results that these value are fairly constant along the whole Boom Clay layer thickness except for the bottom part and the top of the upper transition zone.

5.2.2 Waste inventory and properties

Classification of conditioned radioactive waste

Table 5-2: Characteristics of the three categories of radwaste accorind to the international classification

	Low level	Medium level	High level
Short half-life (< 30y)	A	A	C
Long half-life (> 30y)	B	B	C

NIRAS/ONDRAF considers two groups: the open group (category A) and the geological group (B and C). The geological group waste needs to be isolated permanently from the biosphere. The distinction between category B and C waste is defined by the thermal dissipation: the waste having a power > 20 W/m³ belongs to the category C waste.

The inventory depends on the choices that are to be taken regarding the operation of the seven Belgian Nuclear Power Plants (NPP), and on the reprocessing options.

The original waste production forecasts assumed an operational lifetime of 40 years for the seven existing NPP. The 40 year operation would result in a consumption of 4860 tHM of conventional uranium (enriched U fuel containing 4.0 % ^{235}U), and a consumption of mixed-oxide (MOX) fuel containing 4.93 % ^{239}Pu + ^{241}Pu. Currently a discussion is going on to extend the lifetime of the NPP, which will obviously affect the amount of waste produced.

The main options for reprocessing are (1) the *complete reprocessing option* and (2) the *direct disposal option*:

(1) complete reprocessing consists of the reprocessing of all of the 4860 tU, resulting in the production of 3920 containers of very high-level vitrified waste (ZAGALC class waste) and 6410 containers of structural waste from spent fuel assemblies (HAGALC2 class waste), plus some 70 tHM of existing MOX;

(2) direct disposal implies a no further reprocessing after the first 630 tU (which was contracted), entailing the production of 420 containers of very high-level waste and 820 containers of structural waste; further it results in about 4230 tU non-reprocessed spent fuel and the existing 70 tHM of MOX.

In addition, the NPP fuel reprocessing also results in bituminized waste (sludge resulting from the chemical treatment of liquid waste mixed with bitumen), and in cemented waste (originating from the BR2 reactor).

5.2.3 Engineered barriers

The following barriers are considered in the Belgian disposal system

Primary Waste Packages

Depending on the waste type, the waste matrix can be considered the first barrier:

- vitrified reprocessing waste: borosilicate glass
- other reprocessing waste: bitumen
- spent fuel: original fuel form (pellets)
- cemented waste

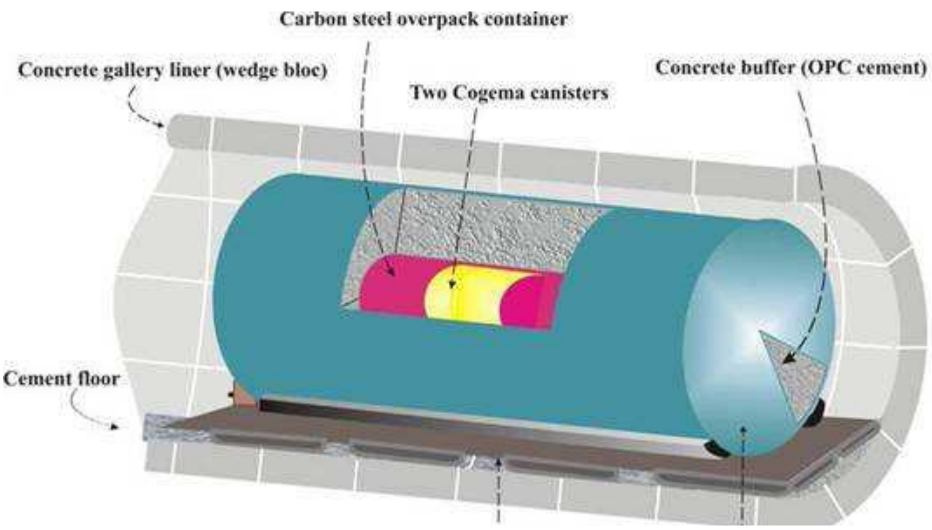
The Primary Waste Packages will be post-conditioned, in surface installations, in a Pre-cast concrete package: the Supercontainer for Cat. C Waste [See References 8 to 13] and the Monolith for Cat. B Waste [6] before disposal in the geological repository.

The Supercontainer

In the Supercontainer (SC) concept, the vitrified HLW canisters or the Spent Fuel assemblies are inserted into a watertight cylindrical carbon steel overpack which is fitted into a concrete Buffer. Specific supercontainer designs have been elaborated: the SC for vitrified HLW from Cogema, three SC for UOX fuel, and the SC for MOX Fuel (Doel 3 and Tihange 2).

The functions of the different components are the following:

- the Overpack has a Long-Term Safety function to prevent contact between the waste form and water coming from the host formation and the engineered barrier during the thermal phase;
- the Concrete Buffer provides a favourable chemical environment (high pH) during thermal phase. The Buffer also provides radiological shielding and allows to avoid the use of “shielded equipments” during the handling and transfer operations;
- the Filler prevents void around the overpack to improve heat transfer and to limit aerobic corrosion during the first years. It consist of a Cementitious grout or a self compacting concrete;
- the Envelope serves as a mould to allow the pouring of the Buffer concrete. It also provides mechanical strength and confinement during transportation and handling and can facilitate retrievability. Note that, if water tightness is imposed (to be confirmed), the envelope then delay coming of water from the host formation. The need of this envelope is still under investigations at ONDRAF/NIRAS and a decision must be taken about the presence of such envelope;
- the space between the overpack and the waste (Spent Nuclear Fuel Assembly or Vitrified Canisters) will be filled with borosilicate glass frit (for HLW canisters) or sand (for UOX and MOX Spent Fuel). The gallery floor will act as a mechanical support to dispose the Supercontainer. Hence, its structural quality is important, since the floor transfers the weight of the disposal package to the structure of the gallery wall. Therefore, the floor should be sufficiently strong, rigid and well anchored to the gallery wall.



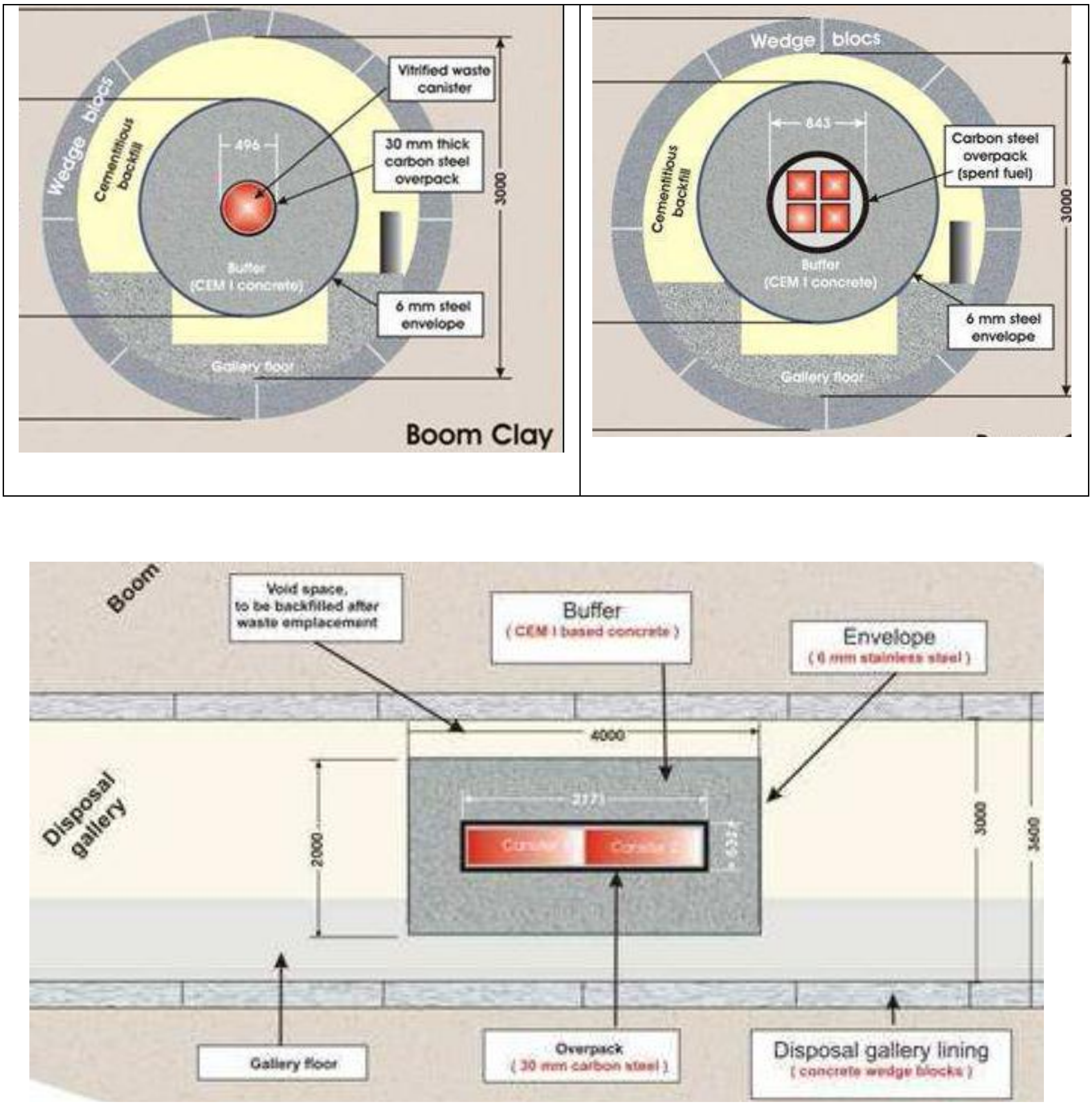


Figure 5-1: Different views of the Supercontainer with an indication of the dimensions

The Monolith

These packages embed the Cat. B waste (bituminized or cemented). The concrete thickness of this package has been assessed taking into account only radiological aspect (shielding of the concrete wall to limit the dose rate at 25µSv/h at 1m). At the post-conditioning facility, primary waste packages are inserted in the pre-cast concrete package, then mortar pouring (eventually through the concrete lid) is performed to fill up and close (i.e. cover) the package.

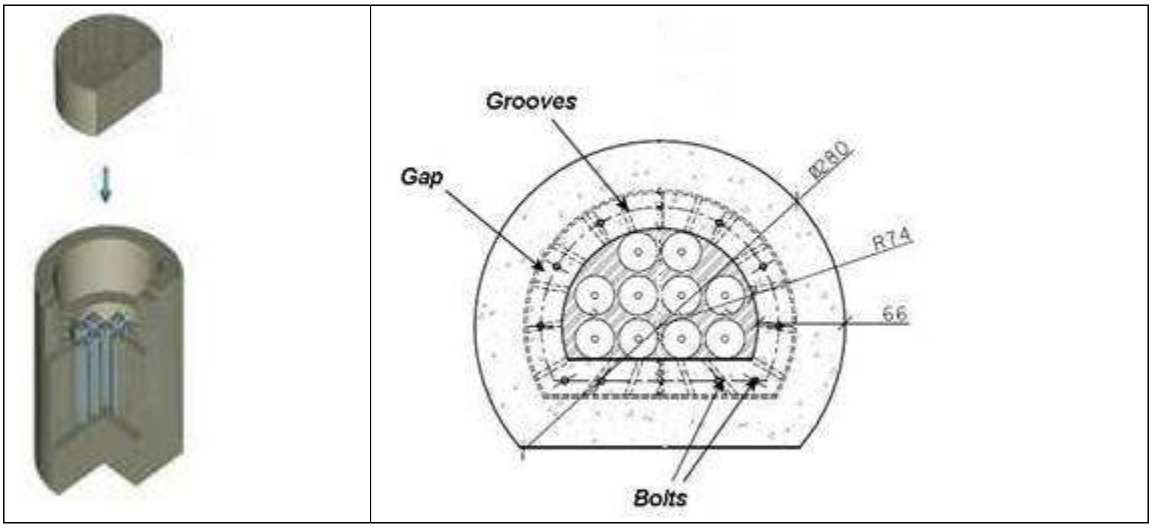


Figure 5-2 The Monolith Concept (Cat. B)

5.2.4 Progressive closure or "one-pass" closure

Progressive closure would be a step-wise closure of disposal cell, drift, fraction of overall repository, … until post-closure

5.2.5 Disposal concept – architecture

definition of overall disposal architecture
definition of disposal cavern, drift, and/or horizontal or vertical borehole

The disposal will be carried out in horizontal disposal galleries; these galleries are excavated in the clay and lined with concrete lining elements; the internal diameter is about 3.0 m. These galleries are constructed starting from the main galleries, which are connected to the surface facilities by access shafts.

The current layout for the disposal of cat. B&C waste is illustrated in Figure 5-3 and comprises three types of construction:

- the surface facilities;
- the shafts, connecting the surface with the underground,
- the underground facilities located at a depth of 230m in one horizontal plane at the medium level of the Boom Clay and with spatially separated sections for Cat. B and Cat. C Waste.
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The different components of the general layout are explained hereunder.

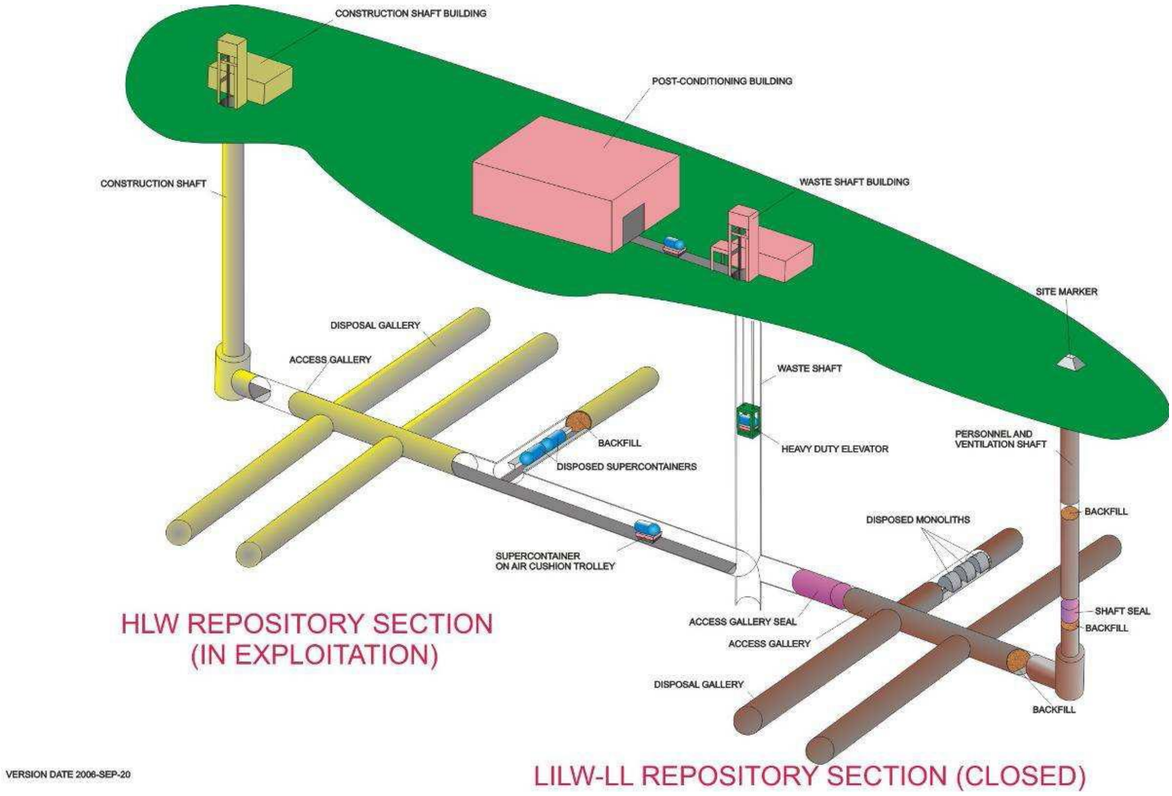

Figure 5-3 Reference Design for the disposal of cat. B&C waste

The surface facilities

The surface facilities consist of:

- the shaft buildings (including hosting tower);
- the disposal packages manufacturing plants (for the fabrication of the Pre-Cast Concrete packages) and the post-conditioning building**s** (for the waste emplacement within these disposal packages, for the closing of these packages (backfilling + closing) and for the intermediate storage before transfer to the underground);
- the technical buildings (i.e. building for the storage of material and equipments for backfilling, …);
- the administrative and other support buildings.

The shafts

In the current design, it is planned to build three shafts:

- the ‘waste shaft’ has a central position. All nuclear waste (B&C) is entered into the repository via the same shaft. This shaft also contains a hoisting system for persons in case of emergency;
- the second shaft is the cat. B repository section construction shaft and provides ventilation to the cat. B repository section and access for the personnel. This shaft is filled and sealed after completion of operations in the cat. B section.
- the third shaft is the cat. C repository section construction shaft. This shaft will be constructed after sealing of the Cat. B Section and prior to the disposal of the cat. C waste.

The underground facilities

The underground facilities include the access and disposal galleries and the starting and mounting chambers.

The access gallery made of wedge block, has a circular shape, is straight and will be constructed in 2 phases (access gallery B for the cat. B section of the repository and access gallery C for the cat. C section of the repository). The access gallery internal diameter is ~ 6 m and the access gallery length is about 1 km. The internal diameter of the disposal galleries is about 3 m. The length of the disposal galleries depends on the waste type and its inventory but is limited to 1000 m. The distance between the disposal galleries vary from 50m (Cat. B and cat C for vitrified waste) to 120m (Cat. C 'spent fuel').

For the crossing between Access Gallery and Disposal galleries:
- no starting chamber is foreseen for the crossing;
- all disposal galleries will cross the access gallery at an angle of 90°;
- per crossing, two disposal galleries are facing each other (fishbone architecture) with blind disposal galleries);
- the infloors are at the same level. Due to the difference of the internal diameters, the axis of the access Gallery and the axis of the disposal galleries are at different levels leading to a complex shape of the intersection between the access gallery and the disposal galleries;
- at crossing, a cast iron lining is used as reinforcement to face the higher bending and torsion stresses due to the opening;
- the excavation diameter of the access gallery will be the same in a normal section and at the crossing in order to keep a constant industrial rate of advance.

The access gallery and the disposal gallery will be outfitted with a concrete floor, specifically designed to provide a path for the transportation. For the disposal gallery, the floor will serve as a mechanical support to dispose the Disposal Waste Packages.
Once 8 Supercontainers or 12 Monoliths B are placed in a section of disposal gallery, backfilling will occur with a cement-based material to prevent « cave-in » in the disposal galleries (i.e. creep of Boom Clay with a risk of host rock destabilization).
The backfill also protects the disposal package in case of gallery collapse (Figure 5-4).

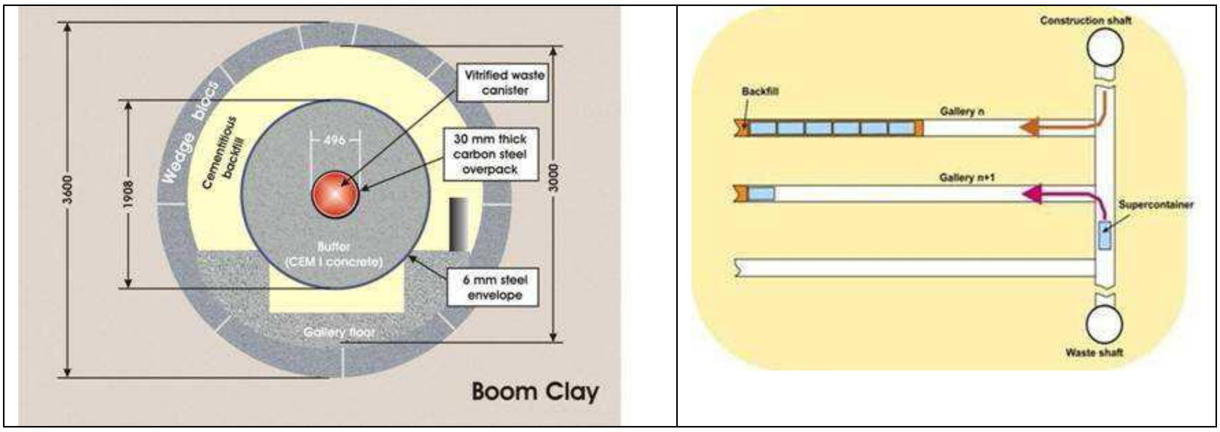

Figure 5-4 Backfilling of the disposal galleries

5.2.6 Disposal concept – definition of upstream disposal process management decisions

Such decisions might be pertaining for example to (i) the need to provide for retrieval or not, (ii) the need to include a well defined, step wise decision process for progressive construction, operation and closure, (iii) thermal management (imposing temperature limits)…

6. Swiss National context (Nagra)

Radioactive wastes in Switzerland are presently in interim storage facilities, the safe operation of which requires continuous monitoring and maintenance activities. Such monitoring, which requires the availability of the necessary technical know-how, cannot be indefinitely guaranteed. It has thus been acknowledged that such storage cannot be considered as a substitute for the final disposal of waste in a deep geological repository (see, e.g., EKRA 2000, Nagra 2002, ENSI 2009).

Nagra's mission is to develop safe geological repositories in Switzerland for all radioactive wastes arising in Switzerland. Two types of repositories are foreseen, one for low and intermediate level waste (L/ILW) and one for spent fuel, vitrified high level waste and long-lived ILW (SF/HLW/ILW). The Federal Government decided in 2006 that Nagra had successfully shown in *Project Entsorgungsnachweis* (disposal feasibility) that safe disposal of SF/HLW/ILW in Switzerland is technically feasible. The project considered Opalinus Clay in northern Switzerland as the host rock. Earlier studies and safety authority reviews in the context of the investigations at Wellenberg had already shown the overall feasibility of safe disposal of L/ILW. Following the *Project Entsorgungsnachweis* decision, the Federal Government initiated the Sectoral Plan for Geological Repositories, which elaborates the siting process. The Sectoral Plan provides a framework within which specific objectives must be met for selecting suitable sites for disposal of both L/ILW and SF/HLW/ILW for which general licence applications are to be made.

Repository implementation involves a stepwise process that will take several decades and includes monitoring as an integral aspect of the concept. There are many aspects of monitoring that must be considered in the context of development of a radioactive waste repository. The broad requirements for monitoring of a disposal facility are outlined in ENSI (2009). These include aspects such as environmental baseline monitoring prior to construction, environmental monitoring during construction and operation, monitoring of the rock and hydrogeological conditions, and radiological monitoring in order to demonstrate compliance with guidelines for radiation exposures from nuclear installations. As many of these are related to the operational phase and are required irrespective of the repository concept, they are not all fundamentally integral to arguments for long-term safety. In addition, requirements for monitoring of a pilot facility are also given. Institutional control after the receipt of the closure licence is not part of Nagra‘s monitoring concept, thus all monitoring activities associated with the repository outlined in the concept would end with the closure of the access tunnel and shaft.

The following sections focus only on monitoring related to the pilot facility, in particular the development of the pilot facility monitoring approach over the last decade.

Implementation of the repositories for radioactive wastes involves a staged process that can be described by the eight phases noted below. The italics represent the specific context for the first three steps for repositories for SF/HLW/ILW and L/ILW in Switzerland:

- Feasibility of final disposal (*Project Gewähr*) (Nagra 1985)
- Siting feasibility HLW *(Project Entsorgungsnachweis)* (Nagra 2002) and overview of siting options for a HLW repository*;* evaluation of sites for L/ILW and development of a project for a general licence application *(Wellenberg*) (Nagra 1997, 1998)

- Evaluation of options and site selection process *(Sectoral Plan for geological repositories and general licence procedure)* (FOE 2008)
- Detailed site characterisation (including underground exploration)
- Construction of facility
- Operation of facility
- Observation (monitoring) phase ('post-emplacement / pre-closure phase')
- Closure of facility

The Sectoral Plan will culminate in applications in about 2016 for a general licence for each of the repositories (or conceivably for a combined repository for both types of wastes). The licensing submission is required to include a document on the concept for the monitoring period and closure of the facility.

The later construction licence applications (ca. 2025 for L/ILW and 2040 for SF/HLW) and Operation licence applications (ca. 2030 for L/ILW and 2050 for SF/HLW) likewise require documents on the monitoring and closure plan. Prior to emplacement of wastes in the repository, an updated project for the monitoring phase is to be completed, including 1) planned measures for monitoring the repository after emplacement of the waste has been completed and 2) the proposed duration of the monitoring period. The application for the closure licence of the disposal facility requires that modifications needed to ensure long-term safety of the pilot facility are presented in a report.

6.1 Societal aspects

Extensive discussion of monitoring in relation to disposal of radioactive waste in Switzerland first arose in the context of the Wellenberg L/ILW project after the negative outcome of the Cantonal referendum in 1995. The EKRA[2] group, established by the Federal Government, proposed adopting the concept of monitored geologic disposal (FOE 2000), as a response to societal wishes concerning monitoring and retrievability. The concept proposed by EKRA foresees a stepwise implementation of the repository including the final part, namely the closure of the repository. A pilot facility should be constructed as the first part of the actual repository, with geometrical and engineering characteristics being the same as the actual repository, albeit with a shorter length of the disposal caverns, and with waste, backfilling material and emplacement cavern seals as in the actual repository. It is this pilot facility that should be monitored extensively, while the main repository is being constructed, filled and closed as planned. An extended monitoring period at the end of the emplacement of all the wastes, in addition to the several decades of monitoring the pilot facility, would provide to the generation at that time a sufficiently long record of observations to decide on the final closure. The idea of a pilot facility was initially incorporated into the Wellenberg L/ILW repository concept (see Figure 6-1) and also became an integral aspect of the HLW repository concept and was incorporated into Project Entsorgungsnachweis (2002b and c).

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[2] EKRA (Expertengruppe Entsorgungskonzepte für radioaktive Abfälle): An expert group established by the Federal Department of the Environment, Transport, Energy and Communication (DETEC).

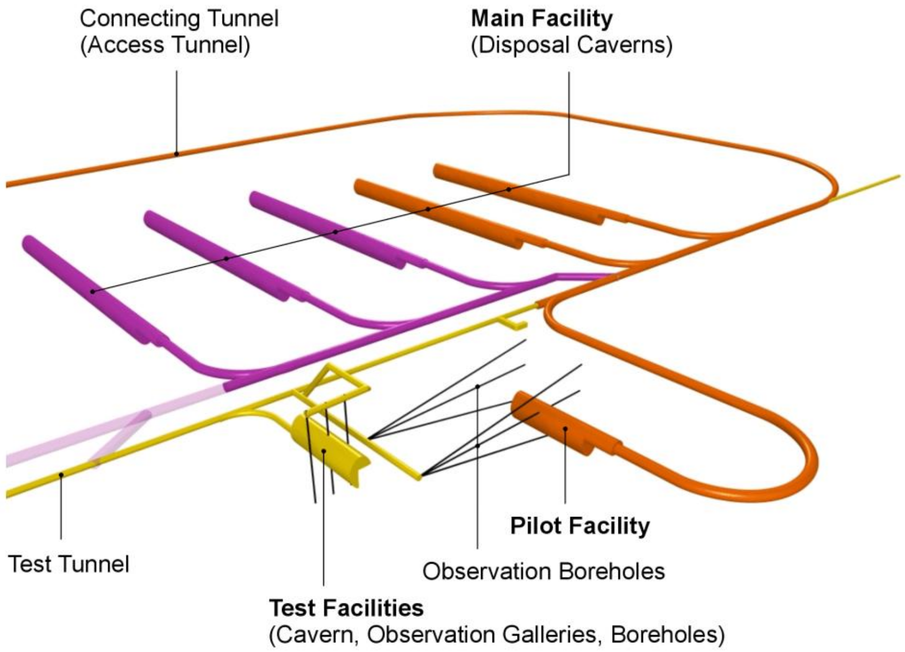


Figure 6-1: Illustration of the monitored geological disposal facility concept for the L/ILW repository

6.1.1 The legal and regulatory framework

The proposal of the EKRA group (FOE 2000) to adopt the concept on monitored geological disposal had a significant impact on subsequent Swiss law and regulations related to geological disposal of radioactive wastes. The Nuclear Energy Act (KEG 2003) and resulting ordinance specified the requirement of the concept of Monitored Geological Disposal, which combines passive safety with a period of monitoring and the possibility of retrievability without excessive effort during the emplacement and observation period until final closure of the repository. The requirements include[3]:

- *Any measures that would facilitate monitoring and maintenance of a geological repository or retrieval of the waste may not compromise the functioning of the passive safety barriers.*
- *The behaviour of the waste, the backfill and the host rock are to be observed in the pilot facility up to the end of the monitoring phase. During monitoring, data are to be collected to support the safety case with a view to repository closure.*
- *The pilot facility is to be designed in accordance with Article 66, paragraph 3 of the KEV and equipped with the instrumentation required for monitoring activities. The pilot facility can consist of one or more caverns or one or more tunnel sections. Incidents in the pilot facility may not compromise the operational and long-term safety of the main facility and vice versa. The possibility of having to transfer waste from the pilot facility to the main facility has to be considered in the facility design.*

The reference to the Article of the KEV (Kernenergieverordnung / KEV) refers to a clause requiring that the pilot facility be hydraulically and spatially separated from the main facility.

The requirements in G03 (ENSI 2009) for the pilot facility include:

[3] The official documents in German should be referred to for any questions of interpretation

- *The pilot facility has to be loaded with waste and backfilled before the start of waste emplacement in the main facility.*
- *It has to be operated in such a way that*
  - *a) the barrier system of the main facility is adequately reproduced and*
  - *b) the selection of waste packages is representative of the inventory of the main facility.*

- *The monitoring programme of the pilot facility must measure the evolution with time of the pilot facility and its geological environment in such a way as to provide information*
  - *a) on safety-relevant conditions and processes in the pilot facility and its geological environment*
  - *b) for early recognition of unexpected developments*
  - *c) on the effectiveness of the barrier system*
  - *d) to support the safety assessment*

- *The information must be transferable to the situation in the main facility and its geological environment.*
- *The suitability of the monitoring programme for the pilot facility has to be checked periodically. The monitoring programme and its results are to be submitted periodically to ENSI for review.*
- *If the condition of the safety barriers of the pilot facility at the end of the monitoring phase no longer fulfils the requirements of safety due to unforeseen processes or planned interventions, and adequate maintenance and repair measures are impossible, the waste has to be removed from the pilot facility and emplaced in the main facility.*

Development of a pilot facility concept that would comply with these requirements is discussed in Section 5.3.

6.1.2 Expert stakeholder expectations

As noted above, the broad expectations and objectives of the EKRA expert group were taken over into the law and regulatory requirements. Nonetheless, these requirements do not specify in any detail the measures to be used to ensure compliance. The specific procedures remain to be determined and Nagra is in the process of elaborating the general approach and potential specific methods.

6.1.3 Lay stakeholder expectations

The appointment of the EKRA group was to some degree a reaction to the Wellenberg referendum of 1995. Nonetheless, the incorporation of a monitoring concept in the revised Wellenberg concept did not result in a positive outcome for the 2002 Cantonal referendum, although other factors may well have been involved.

6.2 Physical aspects

6.2.1 Host rock

As noted in the above in the introduction part at the beginning, the Sectoral Plan for Geological Repositories, under the leadership of the federal government, defines the process for selecting repositories. The overall process is summarized in Table 6-1.

The Sectoral Plan sets out criteria for suitability of host rock and sites, which are given in Table 6-2.

Table 6-1: The 3 main stages in site selection in the Sectoral Plan process

Stage / Main Focus	**Local Participation**
Stage 1: Selection of geologic regions ▪ Evaluation with respect to long-term safety ▪ Evaluation of spatial planning situation and determination of the evaluation methodology to be applied in Stage 2 *Expected Duration: 2.5 a*	▪ Information of the affected cantons, communities, neighboring countries ▪ Information of the public ▪ Establishment of Cantonal Committee
Stage 2: Selection of at least 2 sites ▪ Provisional safety analyses ▪ Site-specific repository system lay-out ▪ Spatial planning and environmental aspects ▪ Socio-economic studies *Expected Duration: 2.5 a*	▪ Build-up of regional participation ▪ Regular information meetings ▪ Cantonal Committee ▪ Regional participation
Stage 3: Site selection ▪ Supplementing geoscientific investigations ▪ Detailed economic studies ▪ Selection of the site	▪ Regular information meetings ▪ Cantonal Committee ▪ Regional participation
General Site License Process *Expected Duration: 2.5 – 4.5 a*	

Table 6-2: Criteria for site evaluation with respect to safety and engineering feasibility.

Criteria group	**Criteria**
1. Properties of the host rock and of the formations contributing to the waste isolation	Spatial extent Hydraulic barrier effectiveness Geochemical conditions Release pathways
2. Long-term stability	Geologic / tectonic stability Erosion Repository-induced effects Resource conflicts
3. Reliability of geological database / statements	Ability to characterise the formations Explorability of the spatial conditions Predictability of the long-term changes
4. Engineering suitability	Geomechanical properties and conditions Underground access and management of inflowing water

Application of the procedure led to the selection by Nagra of 6 geological siting regions for the L/ILW repository (Südranden, Zürcher Nordost, Nördlich Lägeren, Bözberg, Jura-Südfuss, Wellenberg) and 3 geological siting regions for the HLW repository (Zürcher Nordost, Nördlich Lägeren, Bözberg). In three of the geological siting regions (Zürcher Weinland, Nördlich Lägeren and Bözberg), the possibility exists in principle of siting the L/ILW and HLW repositories together as a so-called "combined repository". In the case of proposals for siting regions for a SF/HLW repository, the host rock is Opalinus Clay, which has been described in detail in Nagra (2002). For the L/ILW repository, in addition to Opalinus Clay, other clay-rich sedimentary rocks are also proposed (Nagra 2008).

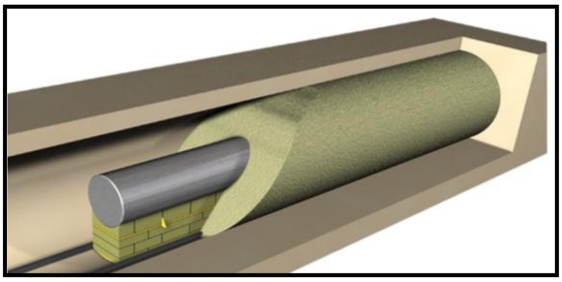
6.2.2 Waste inventory and properties

For the repository for SF, HLW and long-lived ILW the following quantities of waste are projected based on the case of 50 years operation of the existing nuclear power plants and the arisings from medicine, industry and research for the period up to 2050:

- About 1600 canisters of SF assemblies containing 2435 tU
- 730 canisters of vitrified HLW arising from fuel reprocessing
- About 2300 m^3 conditioned packaged long-lived ILW

6.2.3 Engineered barriers

The engineered barrier systems for both SF/HLW and L/ILW are shown in Figure 6-2. The SF/HLW canisters rest on blocks of precompacted bentonite, with the remaining region backfilled with pelletized bentonite. In the case of ILW, cement-based mortars are used to fill the void region after emplacement of the waste containers.



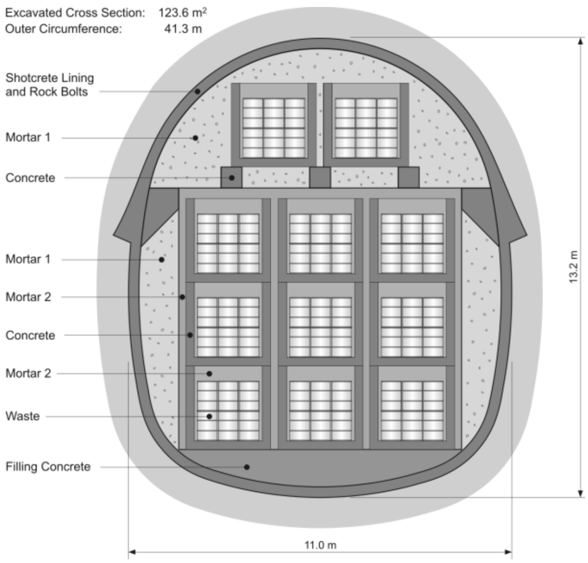


Figure 6-2: The engineered barrier system for SF/HLW and L/ILW

6.2.4 Repository design concept and waste emplacement and sealing procedure

The layout concepts for a repository for SF/HLW/ILW and L/ILW are illustrated in Figure 6-3 and Figure 6-4. The SF/HLW repository concept for Opalinus Clay envisions an array of long (~ 800 m) parallel tunnels at a depth of 600 to 900 m containing the SF or HLW canisters (Nagra 2002). Also included in the SF/HLW/ILW repository are three caverns for long-lived ILW. A pilot facility is required for both repositories and the pilot facility tunnels and the observation tunnel can be seen adjacent to the main facility waste emplacement tunnels.

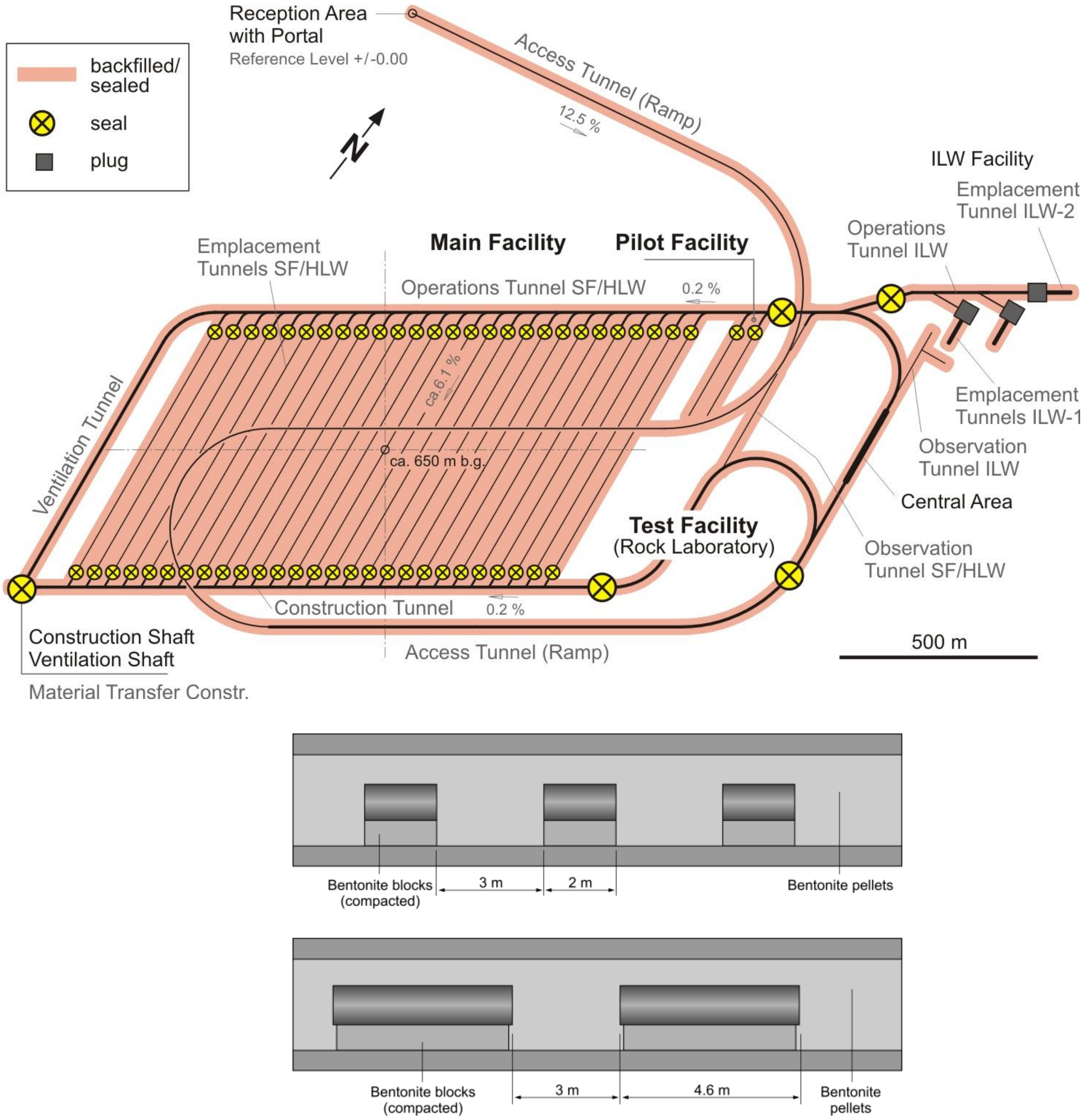


Figure 6-3: Concept for a repository for SF/HLW in Opalinus Clay (Nagra 2002) showing plan view of the facility (top) and cross-sections for the HLW and SF emplacement tunnels (bottom).

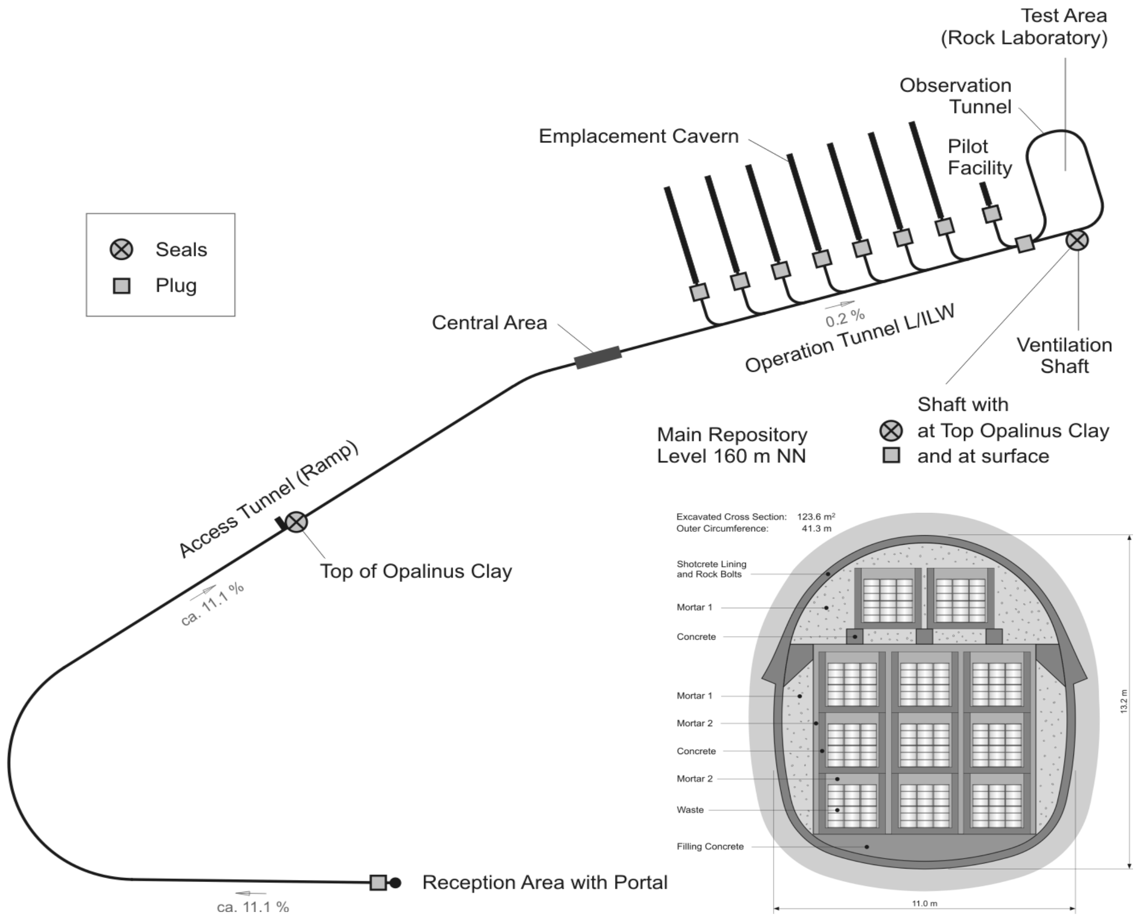


Figure 6-4: Plan view of a repository for L/ILW in sedimentary rock (Nagra 2008), along with cross-section of an emplacement cavern

For the main facility of the SF/HLW repository, the concept involves sequential emplacement of the waste containers and immediate backfilling until an emplacement tunnel is filled, after which a seal is installed at the end of the tunnel. It is important to note that this approach of continuous emplacement and sealing is a formal regulatory requirement stated in G03 (ENSI 2009).

6.3 Considerations and potential implications related to monitoring

The ENSI requirements for the pilot facility provide broad guidance in terms of objectives and constraints for the monitoring and allow an overall concept to be developed.

The main purpose of the monitoring programme of the pilot facility is, according to ENSI (2009), to provide information on the condition, processes and effectiveness of the barrier system and to permit early identification of unexpected developments. The information obtained should support the safety assessment for final closure of the repository. The duration of the monitoring period for the pilot facility is not specified either in Swiss law or by the regulator. It must be proposed by Nagra along with the details of the monitoring plan. The Swiss government would order the monitoring to begin and specify the duration. The possibility to extend the duration exists.

The ENSI requirements are not at present interpreted to mean that providing information on safety-relevant conditions and processes is the same as scientific validation of models. The latter must be done progressively through URL experiments at Mont Terri and at the site URL during the construction phase and must be shown to be completed in a satisfactory way within the framework of obtaining the operating licence. Thus model validation with respect to the evolution of near-field conditions after canister emplacement (thermo-hydro-mechanical behaviour of the bentonite, canister and near-field rock) must be confirmed by the time that the pilot facility is built. This should allow the focus in the pilot facility to be on measurement of some safety-relevant indicators that confirm the barrier system is performing effectively. This should involve confirming that target values of parameters are not being exceeded (or are within certain target ranges). These target values and ranges will be identified and progressively developed during model validation studies in the URLs as more experiments are done and models improve. This approach would significantly reduce the numbers of instruments and the associated disturbances.

Pilot facility tunnels would be excavated with the same method and with the same diameter and use the same rock support methods as would be used for the emplacement tunnels of the main facility. They would be instrumented prior to the emplacement of the waste in order to obtain baseline information. The general concept is illustrated in Figure 6-5 for the case of the SF/HLW pilot repository. In this case two/three pilot facility tunnels with a length of ~100m would be excavated (note that the emplacement tunnels in the main facility would be 800 m long). A small number of HLW and SF canisters with the reference maximum heat output would be emplaced according to the reference method. Adjacent observation galleries would permit instrumentation boreholes to access the rock around the tunnels and, in principle, the near field. The ENSI requirements, however, clearly state that, '*if the condition of the safety barriers of the pilot facility at the end of the monitoring phase no longer fulfils the requirements of safety due to unforeseen processes or planned interventions, and adequate maintenance and repair measures are impossible, the waste has to be removed from the pilot facility and emplaced in the main facility.'* How this would be dealt with remains to be resolved, although it seems clear that extensive instrumentation of both the host rock and near field would be likely to lead to a need to recover the canisters for emplacement in the main facility. All these emplacement activities for the pilot facility should be completed before the beginning of waste emplacement in the main facility.

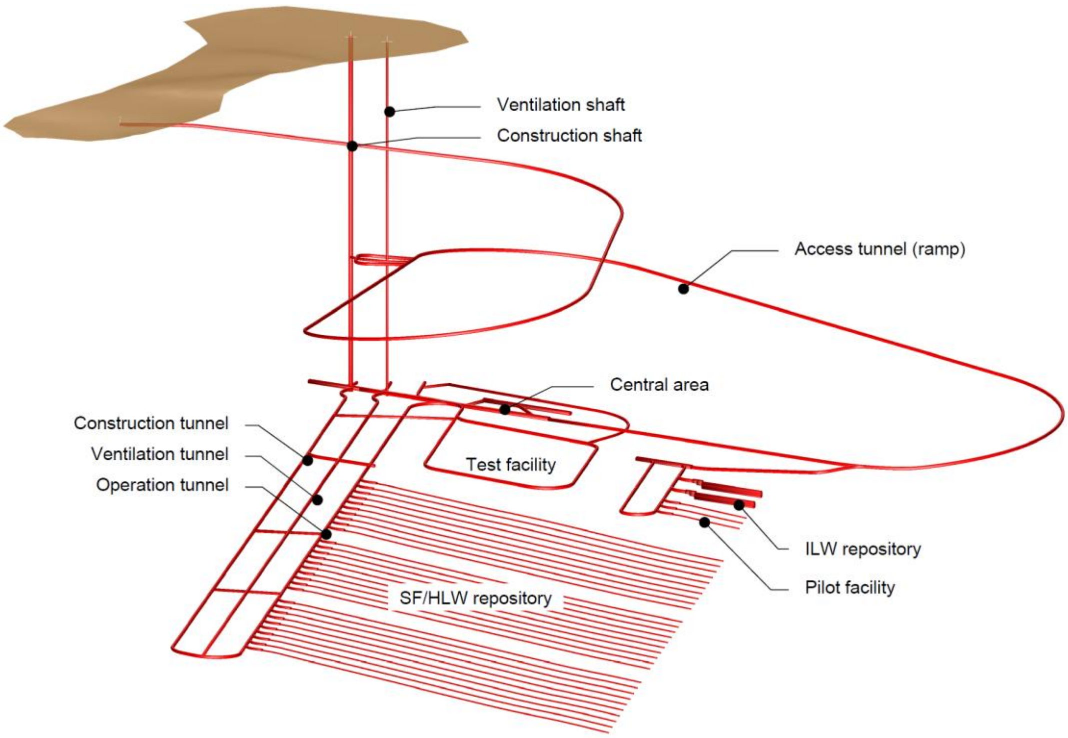


Figure 6-5: General concept of the SF/HLW/ILW repository including the pilot and test facility

In order for the pilot facility to be representative, emplacement of the seals at the ends of the tunnels should also be included.

The parameters to be monitored remain to be determined, but at present temperature at various positions in the near and far field and pore pressure within the rock and at the tunnel boundary would appear to be likely to be required, as target values or ranges that are indicative of sufficient process understanding would certainly be expected to arise from earlier model validation studies. It is also possible, in principle, to sample the gas in the backfill around canisters and to confirm that radionuclide release has not occurred (e.g. fission gases). As noted above, it could be construed that more intrusive approaches involving penetration of the near field and, for example monitoring of the surface temperature of canisters would lead to a requirement to recover the canisters for emplacement in the main facility. Nonetheless, it may be possible through further development of wireless monitoring, that instrument leads can be avoided in some cases. In addition, the recovery of some or all of the canisters in the pilot facility would permit checking of the assumptions regarding early stage corrosion performance. These issues remain to be resolved in future studies.

6.4 References

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Nagra (2008): Effects of post-disposal gas generation in a repository for low- and intermediate-level waste sited in the Opalinus Clay of Northern Switzerland. Nagra Tech. Rep. NTB 08-07. Nagra, Wettingen, Switzerland.

7. UK national context (NDA)

In October 2006, the UK Government and the devolved administrations accepted recommendations from the Committee on Radioactive Waste Management (CoRWM) that geological disposal, preceded by safe and secure interim storage, was the best available approach for the long-term management of higher activity radioactive wastes.

The Nuclear Decommissioning Authority (NDA) is the implementing organisation for the geological disposal facility. Within the NDA, the Radioactive Waste Management Directorate (RWMD) is responsible for delivering the geological disposal programme. RWMD is developing into an effective delivery organisation, to be independently regulated as a prospective ‘Site Licence Company’ by the Nuclear Installations Inspectorate (NII) of the Health and Safety Executive (HSE) and the environment agencies.

NDA RWMD currently has responsibility for implementing Government policy on long-term radioactive waste management for higher activity wastes, which include certain types of low-level radioactive waste (LLW), intermediate-level waste (ILW) and high-level waste (HLW), and radioactive materials that are not currently classified as waste but that may, if it were decided at some point in the future that thay had no further use, need to be managed through geolgical disposal. These radioactive materials include spent fuel, plutonium and uranium.
A framework for managing higher activity radioactive waste in the long-term through geological disposal was set out in a Government White Paper published in June 2008 (Defra 2008), known as the Managing Radioactive Waste Safely (MRWS) White Paper. The MRWS White Paper includes within the framework the Nuclear Decommissioning Authority’s (NDA’s) technical approach for developing a geological disposal facility, including the use of a staged implementation approach and ongoing research and development to support delivery.

The MRWS White Paper defined an approach to implementing the geological disposal facility based on voluntarism and partnership with local communities. The adoption of a partnership approach has significant impacts on the UK monitoring context as described below.

Development of the UK National Context has considered a wide range of inputs, as illustrated in Figure 7-1.

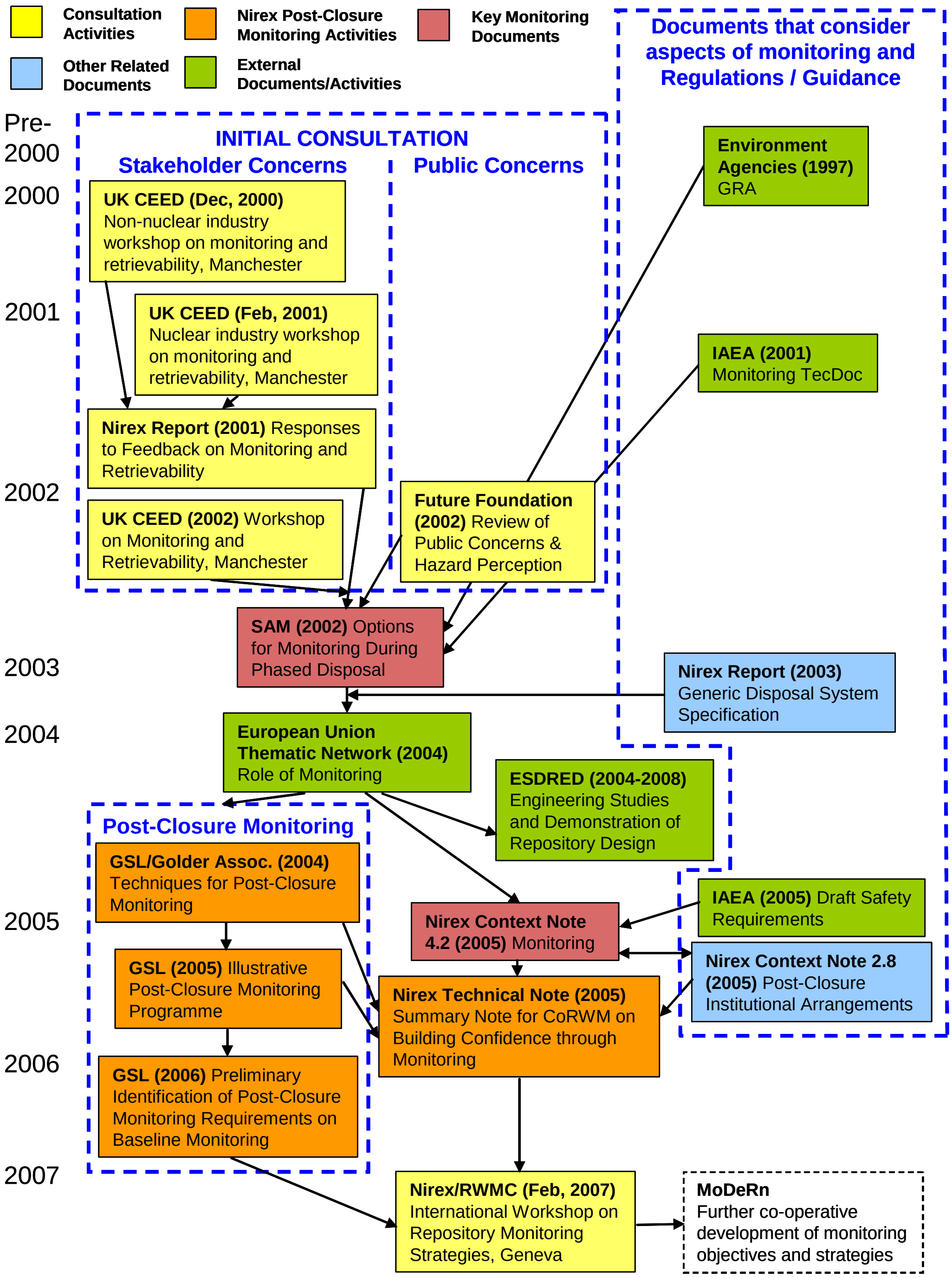

Figure 7-1: Flowchart illustrating key monitoring activities undertaken in the UK and their relation to each other, and to key regulatory/guidance documents.

7.1 Societal aspect

7.1.1 Expert Stakeholders' Expectations

Prior to embarking on work to define its monitoring strategy, UK Nirex Ltd held two workshops in order to understand further stakeholder concerns regarding monitoring and retrievability. The first workshop was held in December 2000, and was with a cross-section of key stakeholders from outside of the UK nuclear industry[4] (UK CEED and CSEC, 2000). The second workshop, held in February 2001, was with representatives from the nuclear industry or companies that are

[4] The participants included stakeholders with little technical knowledge of geological disposal, as well as participants with extensive knowledge of the subject.

(or have been) involved in work for the nuclear industry (UK CEED and Sextant Consulting, 2001).

Responses to the comments received at the two workshops were presented in Nirex (2001a). The comments regarding monitoring included the following issues:

- Technical Issues: Many technical issues were raised in the comments. These included concerns that:
  - There could be a time-lag between a problem with the geological disposal facility and the problem being detected.
  - Instrumentation could fail - there needed to be development of equipment that will last for the periods required in the monitoring programme, and this equipment needed to be tested in demonstration facilities.
  - A monitoring programme should be evaluated against a predictable short-term expected evolution.
  - A monitoring programme should cover several different spatial scales (expressed by workshop participants as relating to waste, rock and environment).
  - A monitoring programme should be able to distinguish between natural and facility-induced processes, to ensure that decision-making was based on performance of the geological disposal facility.
  - The details of a monitoring programme should be specific to the design of the geological disposal facility.
- Strategy: Workshop participants felt that a strategy should be developed that included the response to anomalous data, and that technical monitoring should be undertaken in parallel with monitoring of general issues, such as societal stability. Participants suggested that Nirex develop a "decision-making/action matrix" is developed to deal with the possibility of recording anomalous data.

- Independence: Many comments highlighted the need for a monitoring programme to consider publication and independent assessment of monitoring data.

The participants of both workshops were keen to continue the discussions in another workshop that brought together both groups. Therefore, Nirex organised the Third Monitoring and Retrievability Workshop in February 2002 in Manchester (see Figure 7-1). This workshop also reviewed Nirex's Forward Programme (Nirex, 2001b). Nirex provided feedback to participants on the work done so far in order to obtain their views on how the work should be developed further. The results of the workshop provided more information about the views of various stakeholders on the subjects of monitoring and retrievability and the sorts of issues that they felt needed to be addressed in these areas (UK CEED, 2002). Several of the comments on monitoring are presented below, some of which overlap with the comments made from the earlier workshops (UK CEED, 2002):

- The question was asked as to whether monitoring should be carried out for societal reasons; these would include: the stability of society; public acceptance of an issue; and who monitors the monitors.

- The public perception of monitoring and retrievability is two-sided. On the one hand, monitoring is carried out to show the waste is safe, but on the other hand the need for monitoring can imply that the waste is not safe.

- Stakeholders need to trust those who supply them with monitoring information.

- Monitoring itself needs to be very broad and should include: the environment; waste integrity, safety issues and geotechnical and hydrological aspects of the process.

- There is a need to monitor the parameters which the public feel are important and inspect these at regular intervals. The package behaviour should also be watched continuously to confirm that nothing dramatic was occurring.

- Once a site is determined, continuous monitoring will help to reassure the local community of its safety.

- It should be made clear what would be monitored and over what periods, and what would happen if the results were unexpected.

- Future work should link monitoring to decision points and show how to build in the assessment of the monitoring results to decision making.

- The issue of monitoring and retrievability allows the community some control as opposed to technical issues which they may not fully understand or have control over.

The feedback received in the Third Monitoring and Retrievability Workshop provided helpful input into the development of Nirex's work programme for monitoring and retrievability. Nirex addressed all the issues raised by participants at the workshop (Nirex, 2004a).

7.1.2 Lay-stakeholders' expectations

In 2001 and 2002, Nirex funded research into public concerns and perceived hazards for geological disposal in the UK (The Future Foundation, 2002; Nirex, 2001a; 2004a, 2004b). Public opinions were gathered by holding a series of focus group meetings. Many of the opinions gathered are relevant to development of a monitoring programme for a geological disposal facility in the UK. During the focus group meetings, participants expressed considerable unease about the Post-Closure Phase of geological disposal. Some participants were disturbed by the idea that there would ever be an end to the human management of radioactive waste. They argued that monitoring should continue for as long as the waste exists.

The expectation for development of the geological disposal facility as part of the MRWS programme is that NDA will work in partnership with potential host communities throughout the process of geological disposal facility siting and development. It is principally through this mechanism that the UK Government envisages that NDA will engage with those members of the public and stakeholders who would be most affected by development of a geological disposal facility.

In addition to identification of sites through voluntarism, the UK Government is currently exploring how the disposal programme could be based on partnerships with local communities. This is likely to include the development of local stakeholder groups, and consultation with these groups on key issues affecting monitoring, for example, the extent to which monitoring will be required to demonstrate safety and retrievability and the extent to which the facility will be monitored post-closure.

The NDA already engages widely with the public and with its current stakeholders, consulting on the work covered by its Strategy and Annual Plans, using various mechanisms including a National Stakeholder Group and Site Stakeholder Groups at its sites.

The adoption of a partnership approach to geological disposal facility development has a strong degree of support from many UK stakeholders, including CoRWM and NuLeAF. By a partnership approach, Government means that the host community will work in partnership with the NDA and with other relevant interested parties to achieve a successful outcome. It is the view of the UK Government that experience in the UK and in other countries suggests that a partnership approach is often an effective method to provide opportunities for all parts of a community (i.e. Host Community, Wider Local Interests and Decision Making Bodies) to work together. These are often underpinned by formal agreements between the parties. In this proposed siting process, a partnership could provide a forum for the host community and the implementer to exchange information and views and for the partnership to advise the decision-making bodies and the NDA as implementer in an open and constructive manner.

One of the roles of a partnership in the UK may be to contribute to the work that NDA will do to design, construct and operate a facility. Therefore, this could include discussions about monitoring, and could be a key input to the way that monitoring programmes are developed and the way in which monitoring data are assessed.

7.1.3 Legal and regulatory framework

This section provides the legislative background to radioactive waste management policy in the UK, focusing on legislation and guidance of relevance to monitoring. The following elements are described:

- Key legislation and guidance documents.
- The organisations responsible for setting and implementing UK radioactive waste management policy.
- Policy development in the UK and key stakeholders that influence policy development.
- Key considerations for monitoring.

Principal Organisations and Legislation

UK Law is set out in Acts of Parliament, and is general in nature, specifying policy and high-level requirements. Secondary Legislation is the next tier of legislation and includes Statutes, Orders and Regulations that can be introduced, for example, by the regulators. Regulators may also develop guidance documents that are intended to reflect the regulators' interpretation of legislation and their approach to its enforcement. Although guidance documents are not legally binding, they provide contextual information that may help licensees and other stakeholders to develop appropriate management strategies.

In the UK, nuclear policy is set by UK Government, through the provision of relevant legislation and through funding, specifically as part of energy policy, which is the responsibility of The Department of Energy and Climate Change (DECC).

In the UK, there is not a single radiation protection regulator. Regulation of aspects of the geological disposal facility of relevance to the MoDeRn Project are undertaken by the Health and Safety Executive (HSE) and the environment agencies:

- The HSE is responsible for enforcing work-related health and safety law in Great Britain. The HSE is also the licensing authority for nuclear installations in Great Britain. Through its Nuclear Installations Inspectorate (NII), the HSE regulates nuclear and radiological safety of nuclear installations, which will include a geological disposal facility. Industrial safety of nuclear installations is regulated by the Field Operations Directorate. The Office for Civil Nuclear Security (OCNS) is the division of the HSE that regulates security arrangements in the civil nuclear industry, including the security of nuclear material in transit. The UK Safeguards Office (UKSO) is also part of the HSE and oversees the application of nuclear safeguards in the UK to ensure that the UK complies with obligations.
- The Environment Agency is responsible in England and Wales for the enforcement of environmental protection legislation in the context of sustainable development. It authorises and regulates radioactive and non-radioactive discharges and disposals to air, water (both surface water and groundwater) and land. The equivalent body in Scotland is the Scottish Environment Protection Agency (SEPA) and in Northern Ireland this function is carried out by the Northern Ireland Environment Agency (NIEA). These organisations are collectively known as the environment agencies.

The principals under which the NII regulates nuclear facilities are outlined in its Safety Assessment Principles (SAPs) (NII, 2006).

The environment agencies have responsibility for granting authorisation for the disposal of radioactive waste (and for authorising radioactive discharges), and for enforcing legislation for controlling the creation and disposal of radioactive waste set out in the Radioactive Substances Act 1993 (RSA 93). The environment agencies also regulate non-radioactive discharges under the Pollution Prevention and Control Act (OPSI, 1999). In England and Wales, from April 2008, permits issued previously under the Pollution Prevention and Control Act will be issued under the Environmental Permitting Regulations 2007 (TSO, 2007). The environment agencies are primarily concerned with safeguarding the environment and the public from hazards which may arise from the disposal of radioactive waste.

In February 2009, the Environment Agency and Northern Ireland Environment Agency published Guidance on Requirements for Authorisation of Geological Disposal Facilities on Land for Solid Radioactive Wastes (the GRA) (Environment Agency and Northern Ireland Environment Agency, 2009). This guidance is aimed principally at the developers of proposed geological disposal facilities for radioactive waste and explains the requirements expected of a developer or operator to fulfil when applying to the Environment Agencies for an authorisation to develop or operate such a facility. The guidance sets out the radiological protection requirements and explains the regulatory process that leads to a decision on whether to authorise radioactive waste disposal. The Technical Requirements specific to the monitoring programme required to evaluate changes caused by repository construction, operation and closure are set out in **Appendix A**.

In addition to RSA 93, the Pollution Prevention and Control Act, the NI Act and the Health and Safety at Work Act, the following legislation is relevant to development of geological disposal facilities and may have an impact on monitoring:

- EURATOM Requirements. Cmnd 2919 highlights a Euratom requirement for Member states to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with basic safety standards established under the Euratom Treaty. Currently, radioactive discharges and their effect on the environment are monitored by operators, regulators and other Government and independent agencies. A similar approach may be considered for aspects of monitoring a geological disposal facility.
- Town and Country Planning Act, 1990. Geological disposal facilities will be considered as a development under the Town and Country Planning Act 1990 and require planning permission. The Town and Country Planning Act 1990 implemented EC Directive No. 85/337 as amended by EC Directive No. 97/11, which requires an environmental assessment to be undertaken. This will take the form of a Strategic Environmental Assessment (SEA) integrated within a wider Sustainability Appraisal (SA), and an Environmental Impact Assessment (EIA). The SEA, SA and EIA processes will also provide opportunities for public engagement during the Managing Radioactive Waste Safely programme, as stated in the White Paper of June 2008 (Defra, 2008).

The Health Protection Agency (HPA) provides statements on radiological protection objectives. These typically consider recommendations of the International Commission on Radiological Protection (ICRP). The advice provided by the HPA is considered by the environment agencies in establishing guidance on the requirements for authorisation to dispose, and is the mechanism for the environment agencies to take account of ICRP recommendations.

7.2 Physical aspects

7.2.1 Host rock

The geological environment of the UK is diverse, and contains a range of different host rocks that could prove suitable for hosting a geological disposal facility. These include crystalline rocks, low-permeability sedimentary sequences and bedded evaporites. These different host rocks provide different opportunities for monitoring the geological disposal facility. The siting programme could result in candidate sites being identified that contain any or all of these host rocks. At this stage in the siting programme, it is therefore necessary for research into monitoring to consider all types of geological environment and all host rocks. The UK has recently embarked on a site selection programme based on voluntarism, and, therefore, the geological environments of candidate sites are unknown.

7.2.2 Waste inventory and properties

A part of its work, the Committee on Radioactive Waste Management (CoRWM) put together a ‘Baseline Inventory’ (CoRWM, 2005) of higher activity wastes for geological disposal using data from the 2004 UK Radioactive Waste Inventory (Nirex, 2005a). CoRWM took a prudent approach including the total amounts of radioactive wastes and other materials that could, possibly come to be regarded as waste in the future. Using information from the 2007 UKRWI (NDA and Defra, 2008) the Baseline Inventory has been updated; see Table 7-1, from Defra (2008).

It is not possible to provide at this time a definitive inventory of radioactive waste that would arise as a result of a new nuclear build programme (Defra, 2008). This is because it will depend on aspects such as the reactor type, how many new reactors there are and how long they operate. The size of any programme of new nuclear power stations might impact on whether all of the new waste could be accommodated in the same geological disposal facility as legacy waste.

The UK has a broad range of wastes and materials that are being considered for geological disposal, as set out in the UKRWI. This requires a monitoring strategy that can manage the large volumes and various impacts of the different materials. However, any monitoring strategy will be dependent on the disposal concept and the expected behaviour of the materials in the disposal facility environment as described in the safety case, which are discussed in the next sections.

Table 7-1: 2007 radioactive waste and materials inventory

Materials	Notes	Packaged Volume / m^3	% Volume	Activity / TBq	% Activity
HLW	1,2,3,5	1,400	0.3	36,000,000	41.3
ILW	1,2,5	364,000	76.3	2,200,000	2.5
LLW (non LLWR)	1,2,5	17,000	3.6	<100	0.0
Spent Nuclear Fuel	1,4,5	11,200	2.3	45,000,000	51.6
Plutonium	1,4,5	3,300	0.7	4,000,000	4.6
Uranium	1,4,5	80,000	16.8	3,000	0.0
Total		**476,900**	**100**	**87,200,000**	**100**

Notes

1. Quantities of radioactive materials and wastes are consistent with the 2007 UK Radioactive Waste Inventory (NDA and Defra, 2008).

2. Packaging assumptions for HLW, ILW and LLW not suitable for disposal at the existing national LLWR are taken from the 2007 UKRWI. Note that they may change in the future.

3. The HLW packaged volume may increase when the facility for disposing the canisters, in which the vitrified HLW is currently stored, has been implemented.

4. Packaging assumptions for plutonium, uranium and spent nuclear fuels are taken from the 2005 CoRWM Baseline Inventory (CoRWM, 2005b). Note that they may change in the future.

5. Radioactivity data for wastes and materials was derived using the 2007 UK Radioactive Waste Inventory. 2040 is the assumed start date for the geological disposal facility.

6. It should be noted that at present the Baseline Inventory is based on UK Inventory figures, and as such, currently contains waste expected to be managed under the Scottish Executive's policy of interim near-surface, near-site storage as announced on 25 June 2007 (The Scottish Government, 2007).

7.2.3 Engineered barriers

The MRWS White Paper (Defra, 2008) requires that NDA RWMD considers the development of a single co-located geological disposal facility, if one facility can be developed to provide suitable, safe containment for the Baseline Inventory.

Selection and optimisation of the preferred disposal concept will be undertaken following identification of candidate sites. NDA RWMD consider it inappropriate to define preferred geological disposal options at this stage, and are conducting work on a range of disposal concepts in preparation for siting. In order to provide advice on packaging waste to waste producers and to demonstrate the viability of disposal in the UK, Nirex developed reference disposal concepts for heat-generating waste (HLW and SF) and non-heat-generating waste (ILW/LLW) (Nirex, 2005b). Also, strategic decisions on long-term radioactive waste management, such as those made by the UK Government in responding to recommendations made by CoRWM, require consideration of the viability of disposal.

NDA RWMD is currently undertaking a range of studies to identify options for the geological disposal facility and the process by which the disposal concept will be defined. The first stage in this process has been the review and identification of generic disposal concepts for HLW and SF, and for ILW. Based on two reviews of geological disposal concepts developed in major national programmes (Baldwin *et al*., 2008; Hicks *et al*., 2008), twelve generic HLW and SF disposal concepts and seven ILW concepts have been evaluated with respect to generic geological environments in the UK.

Disposal Concept Implications for the Monitoring Programme

Given the generic status of the UK programme, it is evident that monitoring strategies have to be developed with consideration of a wide range of potential disposal concepts. Therefore, it is necessary for the UK programme to consider general approaches to monitoring and to consider details of how those general approaches would be applied in specific cases, for example those represented by the reference disposal concepts developed for HLW and SF, and for ILW.

The range of concepts that might be implemented in the UK may have significant impacts on monitoring approaches. For example, we might consider cavern disposal for HLW and SF, or tunnels rather than vaults for ILW. The safety functions of the multiple barriers will also influence the monitoring programme. A key barrier for the reference ILW/LLW concept used for packaging advice is the backfill, which provides chemical conditioning. It may be acceptable, after appropriate consideration of impacts on groundwater flow and radionuclide migration, to place sensors within this material to monitor the chemical evolution of the near-field following backfill emplacement. However, the availability of sensors that can withstand the aggressive alkaline environment would first need to be demonstrated.

A particular aspect that has been considered by NDA RWMD is the temporal and spatial evolution of the reference ILW concept used for packaging advice, and initial ideas about the way in which these processes could potentially be monitored following closure of the geological disposal facility should post-closure monitoring be required by future generations (GSL and Golder Associates, 2004).

7.2.4 Progressive closure or "one-pass" closure

The UK Government recognise that some decisions can be made at a later date in discussion with the independent regulators and local communities.

(Defra, 2008)

"Government's view is that the decision about whether or not to keep a geological disposal facility (or vaults within it) open for an extended period of time can be made at a later date in consultation with the independent regulators and local communities. In the meantime the planning, design and construction can be carried out in such a way that the option of extended retrievability is not excluded."

"Government acknowledges that there is a divergence of views on the issue of waste retrievability, but on balance considers that CoRWM's conclusion was correct, i.e. that "leaving a facility open, for centuries after waste has been emplaced, increases the risks disproportionately to any gains" (Ref. 1). Closure at the earliest opportunity once facility waste

operations cease provides greater safety, greater security from terrorist attack, and minimises the burdens of cost, effort and worker radiation dose transferred to future generations."

"CoRWM noted that it is likely to be at least a century from publication of their recommendations in July 2006 until final closure of an entire facility is possible (Ref. 1). In practice it could be longer. This timescale provides sufficient flexibility for further research to be undertaken. Hence Government's view is that the decision about whether or not to keep a geological disposal facility (or vaults within it) open once facility waste operations cease can be made at a later date in discussion with the independent regulators and local communities. Any implications for the packaging of wastes will be kept under review."

7.2.5 Disposal concept – architecture

Given the generic status of the UK programme, it is evident that monitoring strategies have to be developed with consideration of a wide range of potential disposal concepts. Therefore, it is necessary for the UK programme to consider general approaches to monitoring and to consider details of how those general approaches would be applied in specific cases, for example those represented by the reference disposal concepts developed for HLW and SF, and for ILW (see Baldwin *et al*., 2008 and Hicks *et al*., 2008).

A particular aspect that has been considered by NDA RWMD is the temporal and spatial evolution of the geological disposal concept, and initial ideas about the way in which these processes could potentially be monitored following closure of the geological disposal facility should post-closure monitoring be required by future generations (GSL and Golder Associates, 2004).

7.2.6 Disposal concept – definition of upstream disposal process management decisions

Staged Authorisation

The regulation of radioactive waste disposal in the UK is not prescriptive. Therefore, the responsibility for developing a monitoring strategy lies with the implementer (NDA RWMD). It is NDA RWMD's responsibility to demonstrate that the monitoring strategy applied at any site is consistent with principles laid down in regulations and is consistent with the requirements of the GRA.

As defined by the GRA, it will be necessary for NDA RWMD to develop an integrated monitoring plan that considers the overall programme of monitoring to be applied during all phases of the development of a geological disposal facility. The programme will need to consider a wide range of reasons for monitoring, including requirements related to the operational safety, the post-closure safety case, and those related to environmental assessment, including strategic environmental assessment (SEA) and Environmental Impact Assessment (EIA).

The MRWS White Paper (Defra, 2008) states:
"Staged authorisation will bring in a series of important hold points each requiring decisions as the development programme progresses. At each hold point, the NDA's delivery organisation will submit an updated environmental safety case to provide continuing assurance that the site will meet regulatory requirements. If satisfied with the updated safety case, the environmental regulator will grant approval, by means of an authorisation or amended authorisation. This will be subject to conditions and limitations considered appropriate at that time, for development of the facility to proceed beyond the hold point. As well as covering aspects such as management

controls, disposal limits, monitoring and reporting, the authorisation conditions could also specify key actions such as specific research and development work that the environmental regulator requires the NDA's delivery organisation to undertake before the next hold-point."

"Staged authorisation will support open and constructive engagement between the delivery organisation, the environmental regulator, stakeholders and the public throughout the facility development. This engagement will involve stakeholders and the public under the principles set out in Box 4 and will be underpinned by formal consultations at appropriate hold points to help provide assurances that an acceptable development path is being followed."

The Environment Agency has recently confirmed its view that staged authorisation should apply to the development of a geological disposal facility (Environment Agency and Northern Ireland Environment Agency, 2009). The staged authorisation process would include a series of hold points at which the Environment Agency would consider an environmental safety case and grant permission for the facility to be continued to be developed beyond the hold point. The safety cases would be underpinned by ongoing monitoring, and, at each step in a staged authorisation process, the developer would need to implement some form of monitoring, for example, to establish baseline (undisturbed) conditions, to ensure operational safety, or to confirm facility performance and environmental protection.

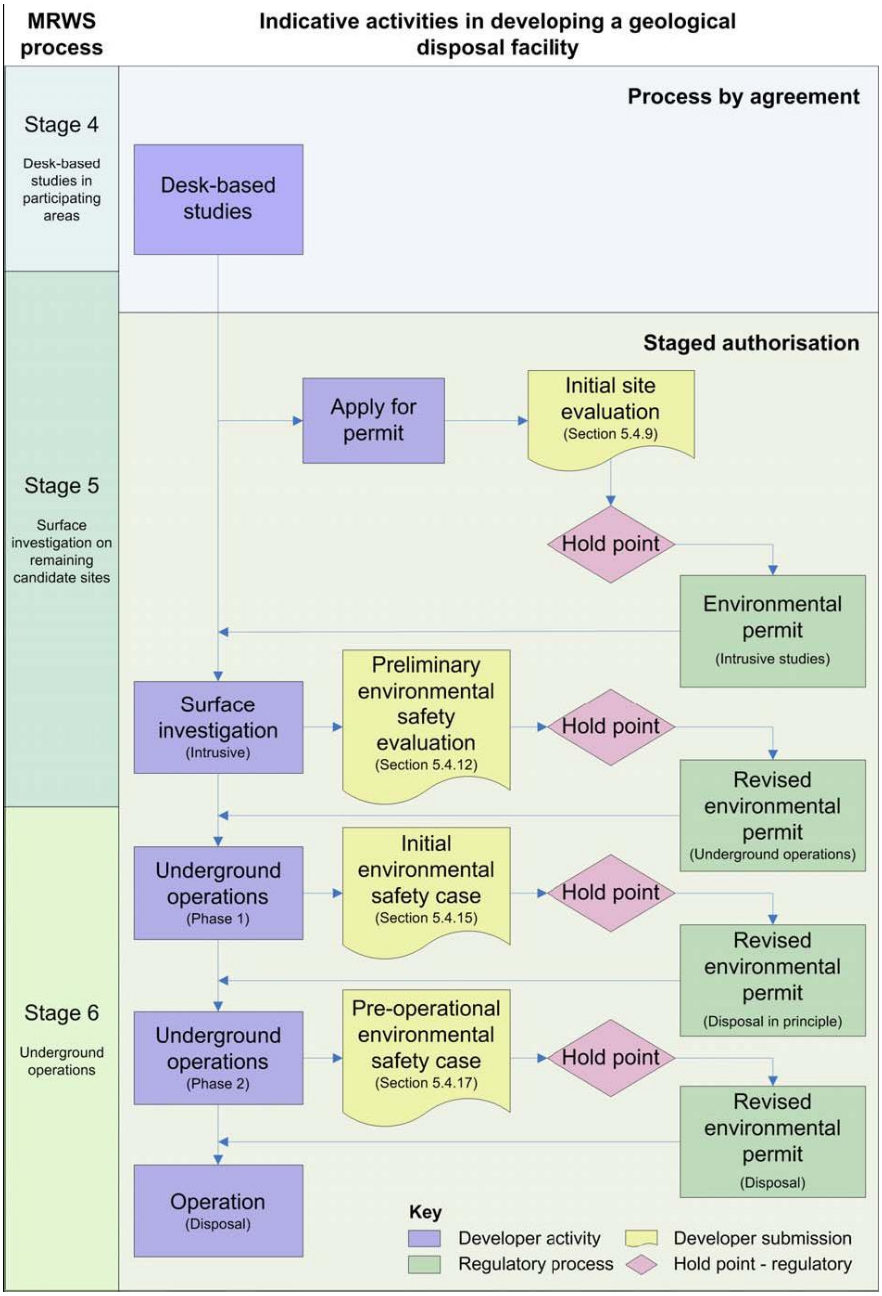

Figure 7-2: Indicative Process for the Staged Authorisation of a Geological Disposal Facility (from Defra, 2009).

Retrievability

An issue that has arisen and been debated during the MRWS programme is how long the facility should remain open for following emplacement of the waste, and whether there should be provision for the waste's retrieval, at least for a period of time (NuLEAF, 2007; 2008). CoRWM considered this issue in some depth and reached the conclusion that early closure was a preferable course of action. Some CoRWM members nevertheless thought that, subject to the views of the UK Government and the regulators, potential host communities should have a say in whether to design a facility for early or delayed closure.

In the UK there is a divergence of views on this subject, which is recognised by the UK Government (Defra, 2007a). However, the UK Government considers that CoRWM's conclusion was correct, i.e. that "leaving a repository open, for centuries after waste has been emplaced, increases the risks disproportionately to any gains". It is the UK Government's view that closure at the earliest opportunity provides greater safety, greater security from terrorist attack, and minimises the burdens of cost, effort and worker radiation dose on future generations. The UK Government also notes, however, as has CoRWM, that it is likely to be at least a century until final closure is possible, which the UK Government believes provides sufficient flexibility for further research to be undertaken to achieve public confidence and approval and to provide for key decisions to be taken in future.

The decision about whether or not to keep a geological disposal facility (or vaults within it) open for an extended period of time will be made, therefore, at a later date. In the meantime, the design and construction will be carried out in such a way that the option of extended retrievability is not excluded, and, therefore, the monitoring strategy will reflect this possibility.

7.3 Decisional process

Elements of the decision-making process to be applied in the conduct of monitoring programmes have been described in the earlier sections of this report. Given the approach taken to implementation of geological disposal of higher activity wastes in the UK, i.e. use of a site selection process based on voluntarism and partnership, it is not appropriate at this stage for detailed monitoring programmes to be defined.

However, development of monitoring programmes for the UK geological disposal facility will take into account the prior information and regulatory background highlighted in this document.

Appendix A

Requirement R14: Monitoring (from Defra, 2009)
"In support of the environmental safety case, the developer/operator of a disposal facility for solid radioactive waste should carry out a programme to monitor for changes caused by construction, operation and closure of the facility.

- *The developer/operator should establish a reasoned approach to a programme for monitoring the site and facility. This monitoring will provide data during the period of authorisation to ensure that the facility is operating within the parameters set out in the environmental safety case. However, the monitoring must not itself compromise the environmental safety of the facility.*
- *In order to provide a baseline for monitoring at later stages, the developer/operator will need to carry out monitoring during the investigation and pre-construction stages. The same measurements may form part of the site investigation programme (see Requirement R11 above). They should include measurements of pre-existing radioactivity in appropriate media, together with geological, physical and chemical parameters which are relevant to environmental safety and which might change as a result of construction and waste emplacement (for example groundwater properties such as pressures, flows and chemical composition).*
- *During the period of authorisation, radiological monitoring and assessment will be needed to provide evidence of compliance with authorised discharge limits and assurance of radiological protection of members of the public. In addition, during the construction stage and the period of authorisation, the developer/operator will need to monitor non-radiological parameters to confirm understanding of the effects that construction, operation*

and closure of the facility have on the characteristics of the site. In particular, the developer/operator will need to demonstrate that the changes in, and evolution of, the parameters monitored are consistent with the environmental safety case.

- *We shall need to be satisfied that the developer/operator has carried out appropriate investigation and monitoring during the construction stage and period of authorisation to establish: the characteristics of the site; the behaviour of the disposal system; and the extent of disturbance caused by intrusive site investigation procedures and by construction, operation and closure of the facility.*
- *The monitoring programme will also need clearly to set out the levels of specific contaminants that will trigger action. It should include an action plan to deal with possible contamination from the facility and an approach to confirming any apparently positive results to avoid inappropriate action being taken in the event of a false positive observation.*
- *In accordance with Principle 4, i.e. that unreasonable reliance shall not be placed on human action to protect people and the environment, assurance of environmental safety must not depend on monitoring or surveillance after the declared end of the period of authorisation. Subsequent monitoring that the developer/operator may wish to include is not ruled out, provided it does not produce an unacceptable effect on the environmental safety case."*

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8. Dutch national context (NRG)

8.1 Societal aspects

8.1.1 Expert stakeholders' expectations

The Dutch "expert" stakeholders are:

- the government regulator: Kernfysische Dienst of the Ministry of Housing, Spatial Planning and the Environment;
- the regional authorities – non-radiological aspects;
- the waste management organisation (WMO) COVRA;
- the waste producers: a.o. EPZ acting for the Borssele NPP;
- the nuclear research organisation NRG;
- academic world (Dutch and international).

In addition, IAEA, NEA, and Euratom can be regarded as international "expert" stakeholders.
No specific expert expectations can be defined except the governmental expectations as defined in section 8.1.3.

8.1.2 Lay stakeholders' expectations

In the Netherlands, responsibility of public information on radioactive waste management is shared between the government and the nuclear sector. As part of this responsibility, the Ministry of Housing, Spatial Planning and the Environment provides a general information on radiation, nuclear safety and radioactive waste management. The Dutch Government gives a base subsidy to NRG for public information on nucleair technology and its applications and participates in European platforms on (among others) transparency in the nuclear industry, such as the High Level Group (regulators) and the European Nuclear Energy Forum (stakeholders).

Transparency and clear communication to the public are important objectives for the nuclear sector. Nuclear companies have the policy that all news, either good or bad, is sent to the media proactively. Most nuclear companies have visitors centres, organize open days and tours of the facilities (for the general public, students, politics and press), and give guest lectures at schools and universities. A platform, Nucleair Nederland (Nuclear Netherlands), was created to exchange national best practices in communication at a national level, and to provide a central contact point for information on all nuclear applications.

8.1.3 Legal and regulatory framework

A central aspect of the Dutch policy on radioactive waste management is a stepwise approach to finding waste management options that are feasible, suitable and acceptable, in both technological and societal respects. Based on three policy documents, published respectively in 1984 [VROM, 1984], 1993 [Dutch Government, 1993] and 2002 [VROM, 2002], the current strategy on radioactive waste management in the Netherlands can be summarized as follows:

- low-, medium-, and high level waste will be stored in purpose-built interim stores at COVRA ("Centrale Organisatie Voor Radioactief Afval"- Central Organization for Radioactive Waste), the Dutch site for aboveground storage of radioactive waste, for at least 100 years;
- ongoing research will be performed on long-term subsurface disposal, preferably in international collaborative programs;
- on the long term, radioactive waste will be stored in a retrievable way in a deep geological disposal.

There are presently several Dutch regulatory requirements and provisions that regulate the protection of the public against hazardous materials. With regard to nuclear energy, the Nuclear Energy Act [Dutch Government, 1963] regulates the protection of people, animals, plants and property. A number of decrees have been issued containing additional regulations. The most important of these in relation to the safety aspects of nuclear installations are:

- the Decree on Nuclear Installations, Fissionable Materials and Ores (Bkse),
- the Decree on Radiation Protection (Bs).
- the Decree on Transport of Fissionable Materials, Ores, and radioactive Substances (Bvser).

The Decree on Nuclear Installations, Fissionable Materials and Ores regulates all activities (including licensing) that involve fissionable materials and nuclear installations. The Decree on Radiation Protection regulates the protection of the public and workers against hazardous ionizing radiation. It also establishes a licensing system for the use of radioactive materials and x-ray emitting devices, and prescribes general rules for their use. The Decree on Transport of Fissionable Materials, Ores and Radioactive Substances deals with the import, export and inland transport of fissionable materials, ores and radioactive substances by means of a reporting and licensing system. The Nuclear Energy Act and the above mentioned decrees are fully in compliance with the relevant Euratom Directive laying down the basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. This Directive (96/29/Euratom) is incorporated in the relevant Dutch regulations.

A general policy in the Netherlands with regard to radioactive waste is that creation and handling of hazardous materials must be controlled and minimized as much as possible, that hazardous wastes must be isolated from the biosphere by safe storage in a disposal facility and that the disposal must be kept under surveillance (IBC-criteria). In principle this implies the storage of waste in facilities that are under institutional control, by shallow land burial and maintenance of a monitoring system enabling long-term surveillance, or by deep geologic disposal.

One relevant consequence of the application of the IBC-criteria to a geological disposal in the Dutch case is the demand that a deep geological disposal must be designed in a way that it includes the principal option for a retrieval of radioactive waste (surveillance/institutional control). Both, maintaining the retrievability option and the demand of surveillance in general require monitoring for an extended period of time; however, the institutional control is likely to be discontinued at some moment in time. For the options mentioned, the degree of institutional control is the highest for storage in buildings and the lowest for deep disposal. The Dutch policy on radioactive waste management does not define the period, in which the option of retrievability has to be maintained or surveillance of a geological disposal is necessary. However, when containment is required over periods of time longer than the existence of current society, doubts may be raised on the capacity of society to fulfil the control requirement.

Geological disposal is especially intended for isolation of long-lived radionuclides, but since the Netherlands has an elevated ground water table, shallow land burial is assumed to be not a reasonable option for the low and medium level waste. Furthermore, as the Netherlands is a coastal state and the possible effects of sea level rising on the long term are largely unknown, an additional uncertainty factor would be introduced. As a consequence deep geologic disposal is projected as a final solution for all waste categories under the assumption that disposal is the preferred management option.

8.2 Physical aspects

8.2.1 Host rock

At present there is no decision made for a host rock that will be used for radioactive waste disposal in the Netherlands, since the Dutch policy requires that radioactive waste will be stored on surface in a dedicated facility for a period of 100 years.

There are however two kinds of host rocks present in the Netherlands that are potentially suitable to host a deep geological repository.

Rock salt
Large domes of rock salt can be found in the North-East part of the Netherlands. In the past several studies have been conducted (e.g. CORA, 2001) in which the feasibility of a deep geological repository in rock salt at depths of 800 m with the option of retrievability have been investigated.

Argillaceous media
Several clay rich sediments of sufficient thickness and depth can be found in the Netherlands. Current concepts are focussing on a Cenozoic deposit, the Boom Clay. The Boom Clay layer can be found almost everywhere in the Netherlands from close to the surface up to depths of more than 1000 m. Dependent on a possible future location of a Dutch geological repository, the precise depth and thickness of this layer are uncertain at the moment. No geological survey of the properties of the Boom Clay layer in the Netherlands is performed yet, but from characterization done within the Belgian programme [NIRAS 2000], some general properties can be derived:

- The major clay mineral is found to be illite (60%), followed by approximately 20% smectitic material, 15% kaolinite and a few percent chlorite.
- For the thermal conductivity, thermal capacity, and thermal diffusion the following value are reported:
  $\lambda = 1.68 \pm 0.04$ W/(mK),
  $\rho{\cdot}C_p = 2.90\ 106 \pm 0.06\ 106$ J/(m^{3}K),
  $k = 0.58\ 10{-}6 \pm 0.02\ 10{-}6$ m^2/s
- For the geomechanical properties of the saturated clay, for the Young modulus, cohesion and friction angle the following values are given:
  $E = 200 - 400$ MPa
  $c = 0.5 - 1$ MPa
  $\Phi = 4°$
- For the hydraulic conductivity, the following best estimated are given:
  $K_{\text{vertical}} = 6{\cdot}10^{-11}$m/s,
  $K_{\text{horizontal}} = 1{\cdot}10^{-10}$ m/s
- The geochemical properties of the Boom Clay pore water can be summarized as follows:
  pH = 8.2
  redox potential = -250 mV
  ionic conductivity = 1.8 mS/cm^{-1}

Not many data are available to estimate the heterogeneity on regional scale, therefore no bandwidth can be derived for the parameter values given above. It is also very likely that a Dutch repository in Boom Clay will be situated significantly lower (i.e. abut 500 m deep) than the Belgian HADES underground laboratory (220 m). The greater depth will influence the (geomechanical) properties of the host rock, and the relevance of this for the construction and the long term safety needs to be analysed.

8.2.2 Waste inventory and properties

Classification of conditioned radioactive waste

Generally, three waste categories can be distinguished, namely low- and intermediate-level waste (LILW), non-heat-generating and heat-generating high-level waste (HLW). In the Netherlands, no distinction is made between short-lived and long-lived LILW. The reason for this is that shallow land burial is not applicable for the Netherlands. All categories of waste will be disposed of in a deep geologic repository in the future. Due to the small amounts of radioactive waste, no separate disposal facilities for LILW and HLW are envisaged. The waste in the storage buildings for LILW is segregated according to the scheme in Table 8-1.

Table 8-1. Low and intermediate level waste classified by type of radioactivity

Category	Type of radioactivity
A	Alpha emitters
B	Beta/gamma contaminated waste from nuclear power plants
C	Beta/gamma contaminated waste from producers other than nuclear power plants with a half-life longer than 15 years
D	Beta/gamma contaminated waste from producers other than nuclear power plants with a half-life shorter than 15 years

HLW, heat-generating, consists of the vitrified waste from reprocessing of spent fuel from the two nuclear power reactors in the Netherlands (Borssele and Dodewaard), the spent fuel of the two research reactors (Petten and Delft) and the spent uranium targets of the molybdenum production.

HLW, non-heat-generating, is mainly formed by the reprocessing waste other than the vitrified residues. It also includes a small amount of waste from research on reactor fuel and some decommissioning waste.

Heat-generating and non-heat-generating HLW are stored in separate compartments of the surface storage facility HABOG which is located in the South-West part of the Netherlands and operated by the Dutch waste management organization COVRA. In Section 8.3 the HABOG facility is described in somewhat more detail.

Given an interim storage period of 50 to 100 years, as discussed in Section 8.3.1, the radioactive inventory that will be produced in the Netherlands and that need to be disposed in the future is not known at this moment. In the CORA programme (CORA, 2001), a future inventory was estimated on the assumption that the Borssele nuclear power plant will be closed in 2004 and no further nuclear power plant would be built and operated in the Netherlands. The resulting inventory would then consist of 300 containers of reprocessed, vitrified high level waste, ten containers of spent fuel from the research reactors, 3000 m^3 of non heat producing high level waste and about 190’000 m^3 of intermediate and low level waste. The present situation however is that the Borssele NPP will be closed only in 2033, which will result in larger amounts of vitrified HLW and other wastes.

8.2.3 Engineered barriers

In the recent TRUCK-NB concept for a Dutch repository in clay (not published yet), the previous TRUCK-II concept [Barnichon et al. 2000] is adapted to the Belgian Supercontainer concept [De Bock et al. 2004], where two high level waste COGEMA container are enclosed by a 30 mm carbon steel overpack and surrounded by 75 cm of ordinary portland cement (OPC). Figure 8-1 and Figure 8-2 shows a representation of a radial and axial cross-section of the Supercontainer concept.

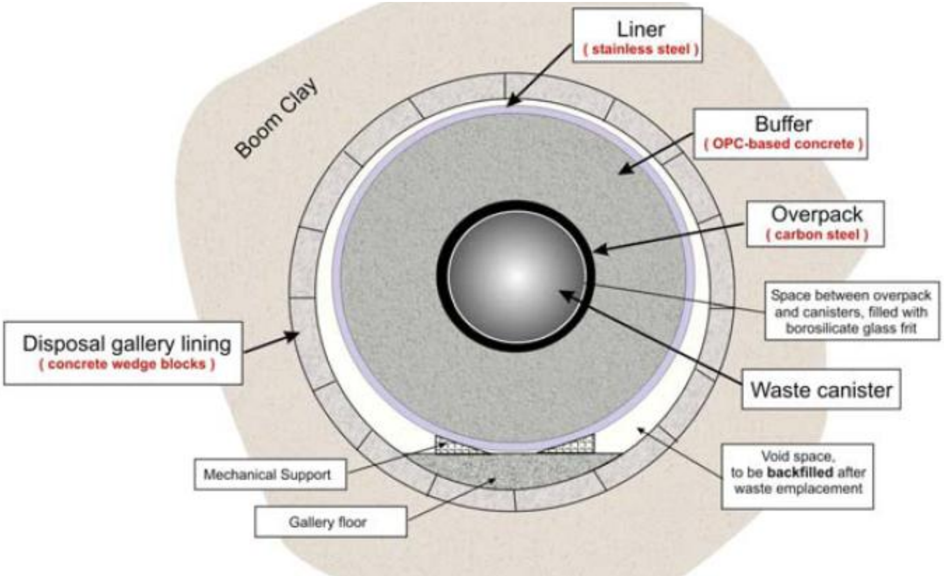


Figure 8-1 Radial cross section of the reference Belgian Supercontainer [De Bock et al. 2004]

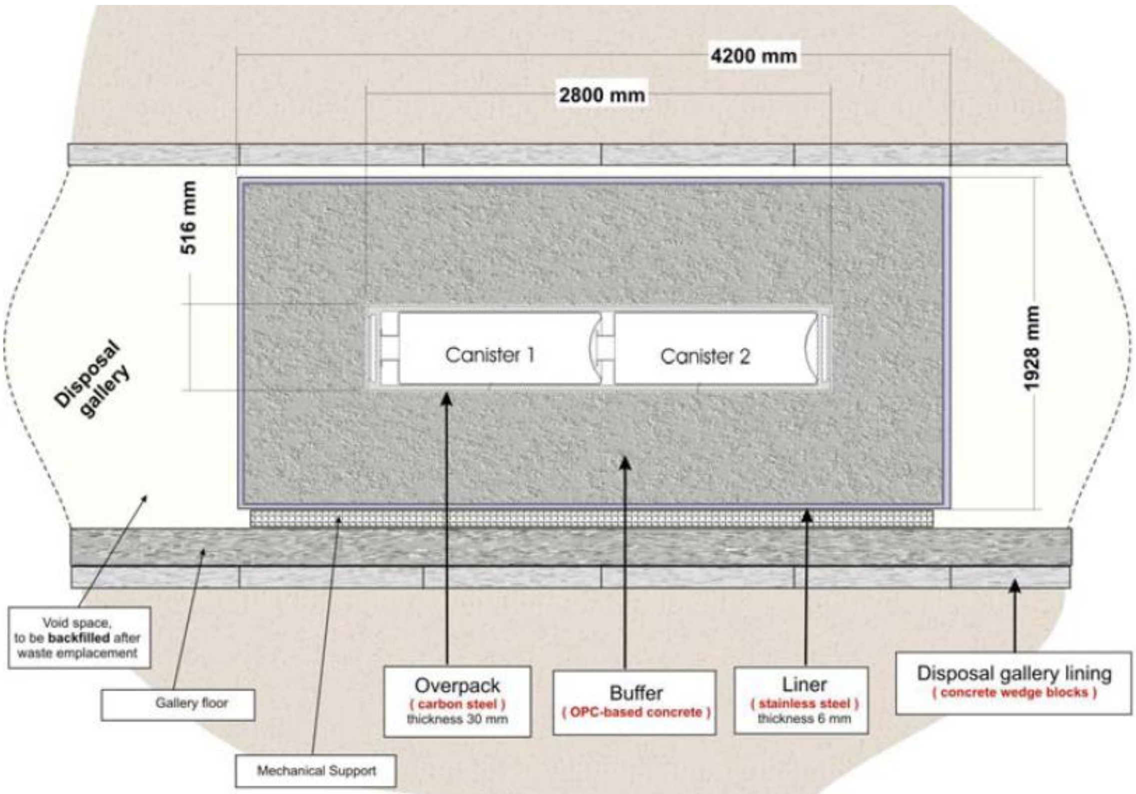


Figure 8-2 Axial cross section of the reference Belgian Supercontainer [De Bock et al. 2004]

8.2.4 Progressive closure or "one-pass" closure

The present concepts for radioactive waste disposal in the Netherlands are still in a conceptual phase and do not address this issue.

8.2.5 Disposal concept – architecture

As stated before, there are two different host rock formations present in the Netherlands that are potentially suitable to host a deep geological repository, viz. rock salt and Boom Clay. For both types of host rocks, disposal concepts have been investigated in the Netherlands.

In the past, the main focus was on the suitability of rock salt to serve as a potential host rock for a deep geological disposal in the Netherlands (Prij, 1993; CORA, 2001). Lately, the focus is shifted to Boom Clay. The two disposal concepts are elucidated in the next sections. The disposal concept in rock salt is only mentioned summarily since NRG has planned most efforts in the near future for the Boom Clay based repository concept.

Disposal Concept in Rock Salt

Figure 8-3 shows the concept of retrievable disposal for radioactive waste in rock salt that has been considered within the CORA program (CORA, 2001). The repository design comprises two vertical shafts each leading to a main gallery. The main galleries are connected by horizontal galleries. The secondary galleries comprise the horizontal boreholes that would contain a single HLW canister per borehole. Plugging of the boreholes is done with pre-compacted salt grit plugs. The salt-based repository would be located in large salt domes that would surround the repository by at least 200 meters at all sides.

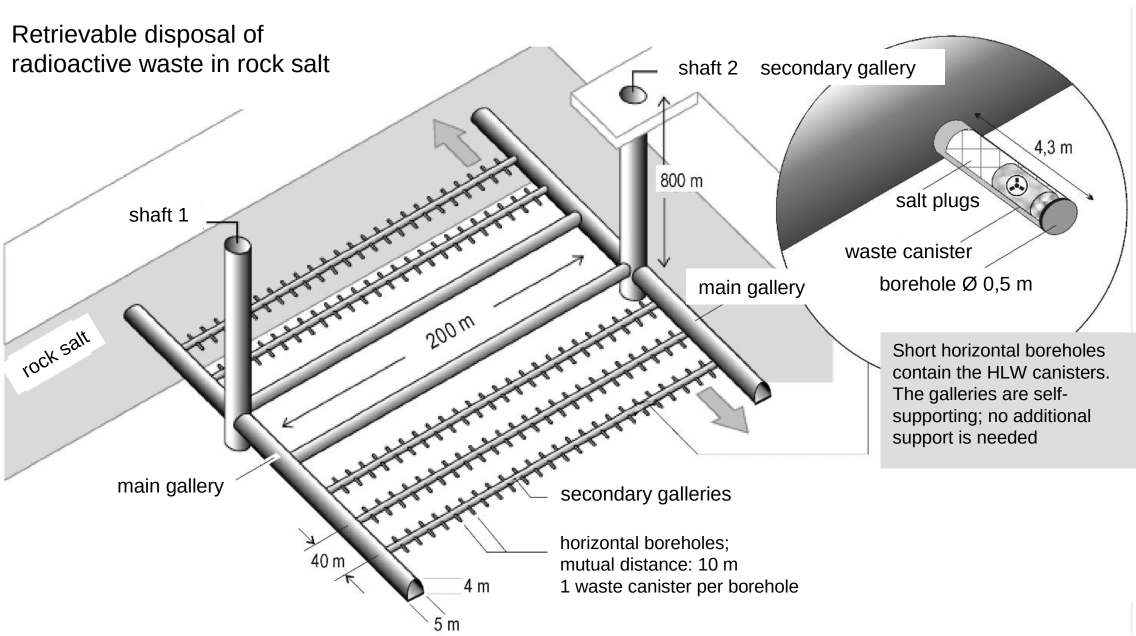


Figure 8-3 Rock salt based option for retrievable disposal of radioactive waste

Disposal Concept in Boom Clay

Definition of overall disposal architecture

The hypothetical repository design for high-level waste and intermediate level waste is based on the *TRUCK-II* design [Barnichon et al. 2000]. The reference repository is located at a depth of 500 m in a 100 m thick clay layer of the Boom Clay formation. The basic configuration considers a planar type of repository, in which all the storage galleries (tertiary galleries) lie in the same horizontal plane at 500 m depth below surface ground. The repository is divided in three sections for different classes of waste (Figure 8-4) and consists of shafts, access galleries, and disposal cells (Figure 8-5). The *TRUCK-II* layout is based on a total number of 320 HLW waste containers. In the zone foreseen to contain heat producing HLW each disposal cell is filled with a single *COGEMA* canister containing vitrified HLW and with a decreasing heat power generation. Upon the termination of the disposal operations, the access galleries and will be backfilled and the shaft will be closed.

Definition of disposal cavern, drift, and/or horizontal or vertical borehole

In the TRUCK-II concept, single COGEMA containers with vitrified waste are stored in disposal cells of 75 cm diameter and 5 meter length. The disposal cells are backfilled with sand and closed with a clay containing material (e.g. bentonite). In the (ongoing) TRUCK-NB project, the original layout of the disposal area of the TRUCK-II project is modified to comply with the new Belgian “Supercontainer” concept [De Bock et al. 2004]: instead of the storage of one single containers in a disposal cell, ten Supercontainers are stored now in a disposal gallery with a diameter of 3 m and a length of 50 to 60 m. For the backfill and closure, several materials are considered.

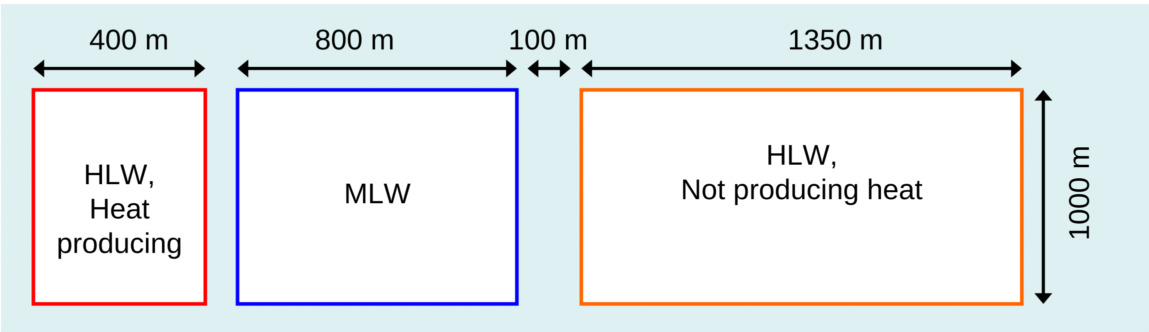


Figure 8-4 Dimensions of the *TRUCK-II* repository design

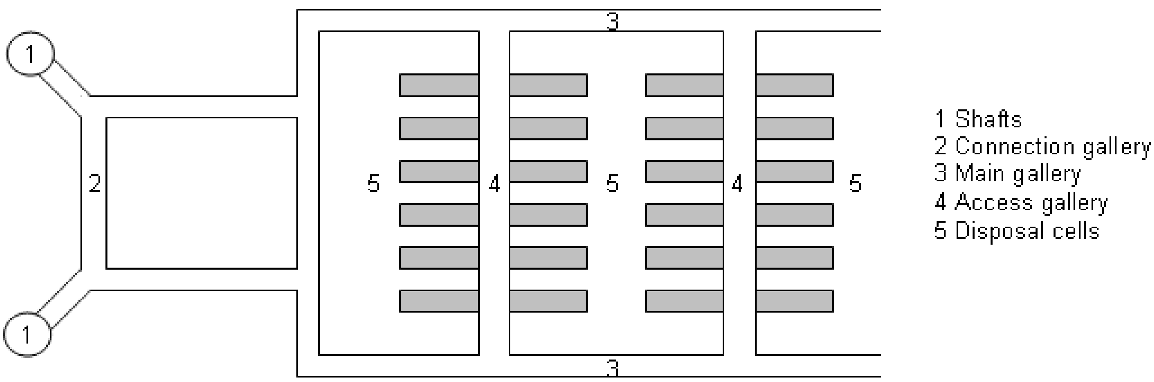


Figure 8-5 Overview of the shaft area and the disposal area

8.3 HABOG - Interim storage facility

In the near future, a geologic disposal of radioactive waste is not foreseen in the Netherlands, since the Dutch policy requires that radioactive waste will be stored on surface in a dedicated facility for a period of 100 years. This dedicated facility, the HABOG, will be described in the next sections after an introduction to the legal and regulatory framework in the Netherlands.

8.3.1 Legal and regulatory framework

The cumulative waste volume in the Netherlands that is in storage at this moment is only a few thousand cubic meters. For the small volume present at this moment it is not economically reasonable to construct a deep geologic disposal facility, but the waste volume collected over a period of 100 years may make a disposal facility more viable. Consequently, it was recommended in the policy report of 1984 [VROM, 1984] that a dedicated solution for the Netherlands is to store the waste in an aboveground facility for a period of about 100 years and to prepare financially, technically and socially the deep disposal during this period in such a way that it can be implemented after the interim storage period. The interim storage of waste over a period of 100 years in an aboveground facility creates a number of positive effects:

- There is a period of 100 years available to allow the money in the capital growth fund to grow to the desired level. This lowers the relative costs per waste unit.
- During the next 100 years an international or regional co-operation with other country may become available. For most countries the total volume of radioactive waste is small. Co-operation creates financial benefits that could result in a higher safety standard and a more reliable control.
- In the period of 100 years the heat-generating waste fractions will be decreased to levels where active cooling is no longer required.
- A substantial volume of the waste will decay to non hazardous levels below the natural background level in 100 years.
- In the next 100 years new techniques or management options may become available.

The concept of aboveground storage gives also the possibility to continue the interim storage after 100 years, to realize the final disposal, or use new techniques or management options that may become available during the period of interim storage.

8.3.2 Waste inventory and properties

Spent fuel and high-level waste

At the HABOG facility the spent fuel of the Dutch research reactors (located in Delft and Petten) is received in dedicated storage and transport casks. These casks are designed to prevent hazards. The spent fuel is repacked inside the HABOG facility in a steel canister, filled with a noble gas (helium) and stored in a noble gas (argon) atmosphere while the special design of the storage vaults provides for shielding and cooling as required. The inert gas atmosphere prevents chemical oxidation during long-term storage. Other hazards such as flooding, gas cloud explosions, airplane crashes, and terrorist actions etc. were taken into account in the design of the facility.

All spent fuel from the Dodewaard NPP has been removed from the storage pool and transferred to Sellafield, UK, for reprocessing. The remaining waste will be returned to the Netherlands and shipped to COVRA for long-term storage.

Spent fuel from the Borssele NPP is kept in storage in the spent fuel pool at the reactor site. After a cooling period of 1 to 3 years (dependent on the safety requirements of the transport packages and the reprocessors' specifications), the spent fuel is transferred to La Hague (France) for reprocessing. Regular transports ensure that the fuel pool inventory is kept to a practical minimum, as required by the plant operating license.

The postponed closure of the Borssele NPP implies an extra 30 years of waste and spent fuel generation, for which additional capacity at COVRA will have to be built, and for which extra capacity in the future disposal facility will have to be reserved. The owner of the Borssele NPP will have to pay for the extra costs. Until today, in the Netherlands no license application for a new NPP was received. In the case a new NPP would be built in the Netherlands, corresponding additional storage and disposal capacity will have to be accounted for.

The COVRA-site allows for these expansions, as it was originally designed for a much larger nuclear programme. Basically, above-mentioned developments will have no impact on the national policy on radioactive waste and spent fuel. However, the additional 30 years of waste generation, as well as an additional 30 years of cost contribution to the disposal fund may mean that within a shorter period than 100 years a geological repository could become economically feasible.

Low and intermediate level waste
The radionuclide content of the waste delivered to COVRA is declared and assured by the waste producer. For the **LILW** four categories are distinguished:

- alpha contaminated waste
- beta/gamma contaminated waste from nuclear power plants
- beta/gamma contaminated waste from producers other than nuclear power plants with a half life longer than 15 years
- beta/gamma contaminated waste from producers other than nuclear power plants with a half life shorter than 15 years

During treatment and conditioning the categories are kept separate. The price of radioactive waste is a financial incentive to segregate at the production point as much as possible radioactive and non-radioactive materials. Treatment of LILW occurs in a special building, the waste processing building (AVG). Drums of waste collected from licensees from all over the country are sorted with respect to type and/or processing method to be applied. The following categories are distinguished:

<u>Vials containing scintillation liquid</u>
The vials are crushed. The liquid is collected and, if possible, separated in an organic and an inorganic part. The organic liquid is burned in an incinerator, the aqueous liquid is treated and the resulting radioactive residues are solidified and conditioned with cement. The solid components are supercompacted and conditioned with cement grout.

<u>Liquid waste</u>
Unless their composition is exactly known liquids are considered as mixtures of organic and inorganic components. Upon treatment the radioactivity concentrates in the deposit and can be separated by filtration. The purified aqueous liquid is then almost free of contamination and can be discharged within the authorized limits. The radioactive residue is conditioned with cement grout. Liquids that cannot be treated in the water treatment system are incinerated.

Animal carcasses
Carcasses of laboratory animals, which are contaminated with radioactivity, are burned in a dedicated incinerator. The ashes are collected, supercompacted and immobilised with cement grout.

Compactable waste
Most of the volume of radioactive waste collected by COVRA is solid compactable waste. Its volume is reduced by compacting the waste-containing drums which are transferred to drums with a larger diameter and consolidated with cement. The conditioned waste is transferred to the storage building.

Sources and other waste
Used sealed radioactive sources are mixed with cement and stored in drums. Other radioactive waste consisting of large sized components is first pre-compressed, or sheared and cut to fit the compacting drums. Again conditioning for long-term storage is done with cement grout.

8.3.3 The HABOG facility

Except for radioactive wastes with a half-life less than 100 days, which is allowed to decay at the sites where it is being generated, all radioactive waste produced in the Netherlands is managed by COVRA, the Central Organisation for Radioactive Waste. COVRA operates a facility at the industrial area Vlissingen-Oost in the south-west of the country, the “HABOG” facility (“Hoogradioactief Afval Behandelings- en Opslag Gebouw”, High-level Waste Treatment and Storage Building).

The HABOG facility is designed to store spent fuel (SF) from the research reactors, vitrified waste from reprocessing and other HLW from reprocessing, decommissioning, research activities or molybdenum production. In November 2003 the first spent fuel from the High Flux Reactor (Petten) was stored, followed in 2004 by vitrified waste from reprocessing in France and by spent fuel elements from the research reactor in Delft. At the end of 2007, 140 vitrified glass canisters, 18 spent fuel containers from the research reactor in Delft, 18 spent fuel containers from the HFR in Petten as well as 2 containers with spent uranium targets from molybdenum production were kept in storage, amounting a total of 29.6 m^3 HLW. A schematic cross-section of the HABOG facility is depicted in Figure 8-6.

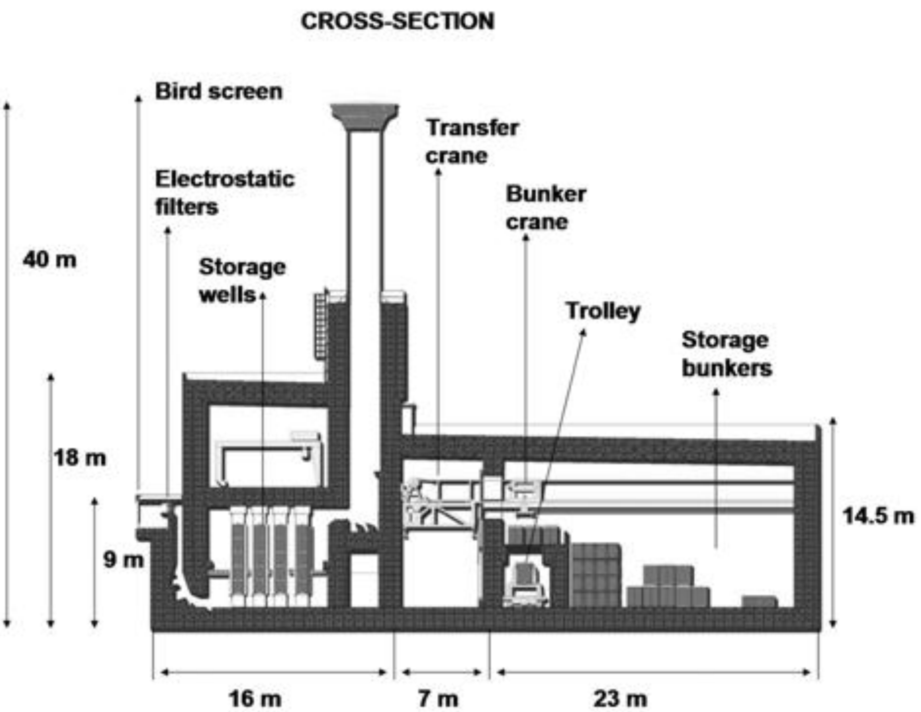


Figure 8-6: Cross-section of the HABOG facility


Figure 8-7: Storage wells for SF and HLW in the HABOG

The HABOG is a vault type storage facility divided in two separate compartments. The first compartment is used for the storage of vitrified HLW from reprocessed SF originating from the NPP's and for SF originating from research reactors. SF and vitrified HLW are stacked on 5 levels in vertical air-cooled storage cells. The storage cells are filled with an inert gas to prevent corrosion of the canisters and are equipped with a double jacket to allow passage of cooling air. A double jacket ensures that there is never direct contact between SF or waste canisters and the cooling air. The cooling system is based on natural convection. Figure 8-7 shows a picture of the storage compartment for SF and vitrified HLW.

The second compartment is used for the storage of drums and other packages containing high level waste that does not need to be cooled (hulls and ends and other high level radioactive waste).

Because of the long-term storage requirement, the design of HABOG includes as several passive safety features. In addition, precautions are taken to prevent degradation of the waste packages. In the design of the storage vault all accidents with a frequency of occurrence larger than once per million years were taken into account in a way that these accidents cause no radiological effects in the environment.

8.3.4 The HABOG and Operational Safety

The principles of the IBC-criteria also apply for the HABOG. For the design of the HABOG the guidelines from ANSI/ANS 57.9-1992 have been applied. Broken down to the abovementioned operational safety principles the following requirements should be fulfilled [Joint Convention, 2008]:

Isolation:

- SF (or radioactive waste in general) should be contained in a way that at least two barriers to the release of radioactive material are present.
- Adequate shielding of the radiation emitted by the waste should be maintained.

Control

- Assurance of a condition of sub-criticality of the SF by application of neutron absorbers and by a suitable geometry of the SF.
- Assurance of adequate cooling of heat-generating HLW.
- Possibility to move SF or HLW from the storage wells with a view to repackaging, relocating to another storage compartment or removal from the facility.

Monitoring

- Monitoring the containment of the storage wells, the temperature of the wells, the shielding capacity and the emissions by inspections and/or measurements.

These requirements have been implemented in the following ways:

Isolation:

- The presence of at least two containment barriers between the SF/HLW and the environment is achieved by passive components, constructions and materials such as the immobilization matrix of the material itself, by the packaging, by the storage wells and by the construction of the building.
- Adequate shielding is achieved through the presence of 1.7 m thick concrete walls.

- The HABOG facility is designed to withstand 15 different design basis accidents in order to prevent consequences for the population or the environment. These design basis accidents include flooding, fire, explosions in the facility, earthquakes, hurricanes, gas explosions outside the facility, an aircraft crash, a drop of a package from a crane etc. The robustness of the construction of the building ensures that none of these accidents, whether arising from an internal cause or initiated by an external event, will result in a significant radiological impact.

Control
- Sub-criticality is maintained by assuring that both under normal operating conditions and under accident conditions the reactivity factor will never exceed a value of 0.95.
- Permanent cooling of the canisters with SF and high level radioactive waste is assured by using a passive air convection system. Calculations have demonstrated that the thermal specifications of the SF/HLW will never be exceeded.
- The HABOG facility is laid out in such a way that there is always one spare storage compartment for each category of waste available.

Monitoring
- The ventilation system is composed of two separate systems: a passive system, based on natural air convection (SF and HLW requiring cooling) and a mechanical system (other HLW). In the former system the ventilation air is never in contact with any radioactive material or contaminated surfaces and is, consequently, not monitored. In the latter system the ventilation air is passed over filters before being released through the ventilation stack. This system is designed in such a way that the air flows from areas with no or low contamination to areas with a potentially higher contamination.

8.3.5 Radiation Protection of the Public and the Environment

As part of the surveillance and prescribed in the operating licence of the COVRA interim storage facility, all emissions of radionuclides from the facility must be monitored, quantified and documented. At COVRA, next to all legal limits, the ALARA principle applies ("as low as reasonably achievable"). This principle will also be valid for any future geological disposal facility. Protection of the public and the environment against the effects of abnormal operational conditions, such as accidents, is ensured by design features of the buildings and installations (multi-barrier system).

The licensee (COVRA) must report the relevant data on emissions and radiological exposure of workers and the public to the regulatory body. On behalf of the regulatory body, the National Institute for Public Health and the Environment (RIVM) regularly checks the measurements of the quantities and composition of any emissions. Next to on-site measurements, the licensee is also required to set up and maintain an adequate off-site monitoring programme. This programme includes measurements of radiation levels in the air, in water, or in grass and milk in the vicinity of the installation. Both the licensee (COVRA) and the RIVM monitor the radiation levels at the border of the facility continuously. The results are reported to - and regularly checked by - the regulatory body. Under Article 36 of the Euratom treaty, the discharge data must be submitted to the European Commission each year.

8.3.5.1 Monitoring at the surface interim storage facilities at COVRA

As already stated monitoring is an important aspect of the safety of the surface storage facility for high-level waste 'HABOG'. The monitoring strategy that is preformed at the HABOG will be discussed in the next section. In addition, the COVRA hosts two innovative non-routine monitoring projects for the spatial characterization of LLW/ILW on different scales, which are executed in cooperation with NRG. The subsequent sections provide more details about these distinct monitoring activities.

8.3.5.2 Monitoring in the HABOG

The monitoring program at the HABOG facility consists of two parts:

- Monitoring during normal operation, i.e. all activities outside the so-called "campaigns";
- Monitoring during "campaigns, which comprise the receipt, the processing and the storage of high-level radioactive waste in the HABOG.

Monitoring during normal operation

The monitoring activities in the HABOG during normal operation comprise two types of measurements:

- Continuous measurements - these on-line contamination measurements are continuously visible on the device itself and in the control room;
- Periodical measurements – these measurements are done by means of air samplers at different locations, and in the exhaust water of the facility.

Table 8-2 gives an overview of the locations in the HABOG that are monitored, and the parameters that are measured during normal operation. The measurements are performed using commercially available standard equipment.

Table 8-2: Locations and parameters monitored in the HABOG facility during normal operation

Contamination Monitoring			
	Location	**Parameter**	**Sampling Rate**
Continuous, on line	Work room of hot cells	α, β activity in particulate matter	Continuous
	Unloading room	α, β activity in particulate matter	Continuous
	Inspection room	α, β activity in particulate matter	Continuous
	Chimneystack[1]	Krypton activity in exhaust air	Continuous
Periodical	*Air samplers*		
	Chimneystack	α, β, γ activity	2 Weeks
	Chimneystack	Tritium activity	1 Month
	Bunker ventilation	α, β, γ activity	2 Weeks
	Vault	α, β, γ activity	Once per year 2 Weeks
	Exhaust water samplers		
		No details available	
Dose Rate Monitoring			
	Location	**Parameter**	**Parameter**
Continuous, on line	Most rooms and corridors in the HABOG	γ dose rate	Continuous
	Filter streets	γ dose rate	Continuous
Periodical	Outside HABOG building	(equivalent) dose rate	After each campaign
	Terrain boundary	(equivalent) dose rate	After each campaign

[1] The "Chimneystack" is the exhaust of the HABOG ventilation system, viz. the passive air-cooled system for the heat-producing HLW canisters

Monitoring during campaigns

Measurements of contamination and dose rates during campaigns are subdivided into 4 phases:

1. Measurements on the transport vehicle and the container during the arrival in the HABOG (container arrival);
2. Measurements on the container, the canister(s), tools, and air (container control);
3. Measurements on the container and the transport vehicle before departure from the HABOG (clearance of the container for transport);
4. Measurements in the rooms after the processing of the waste (room clearance)

The procedures followed during these four phases differ somewhat dependent on the type of waste that is received in the HABOG, i.e.

- MTR2 containers, holding spent fuel from the two research reactors in the Netherlands;
- CSD-V containers, holding vitrified high-level waste (HLW)
- CSD-C containers, holding compacted waste – the radiological controls are similar to those applied to the CSD-V containers.

Table 8-3: Locations and parameters monitored in the HABOG facility during campaigns

Phase	Monitored Item	Parameter
MTR2 Campaign (spent fuel from research reactors)		
1. Container arrival	• transport vehicle • container	• α-, β, γ-contamination (wipe test) • γ-dose rate
2. Container control	• container • canister • tools • air	• α-, β, γ-contamination (wipe test, air samplers) • dose rate • γ-dose rate • krypton activity
3. Container clearance, before leaving the HABOG	• empty container • transport vehicle	• α-, β, γ-contamination (wipe test) • γ-dose rate
4. Room clearance	• processing room	• contamination*
CSD-V (vitrified high-level waste) and CSD-C (compacted waste) Campaigns		
1. Container arrival	• transport vehicle • container	• α-, β, γ-contamination (wipe test) • γ-radiation • neutron radiation
2. Container control	• container • canister • tools • air	• α-, β, γ-contamination (wipe test, air samplers) • γ-dose rate • neutron radiation • krypton
3. Container clearance, before leaving the HABOG	• empty container • transport vehicle	• α-, β, γ-contamination (wipe test) • γ-dose rate
4. Room clearance	• processing room	• contamination*

* no details provided

Monitoring redundancy

The state-of-the-art passive air-cooled system for the heat-producing HLW canisters releases the heat produced by the HLW through the “Chimneystack”, i.e. the exhaust of the HABOG ventilation system. The ventilator in the stack sampling line, through which gas samplings are taken for monitoring purposes, is implemented redundantly. The stack α + β aerosol samplers are realized in duplicate. All on-line, fixed measuring systems are equipped with both optical and acoustical alarms. In the case of a malfunction or defect of the samplers the doors will be locked.

Purpose of the measured data
The purpose to perform the mentioned measurements is to monitor dose rates and any air contamination. Upon exceeding pre-established limits, optical and acoustic signals warn the personnel. Subsequently, the entrance to certain rooms and spaces are blocked and other measures are taken.

Calibration and Testing
All radiation measuring equipment at the COVRA site is subject to regular control and, in addition, some equipment is calibrated every two years. Calibration is performed on dose rate monitors and neutron monitors by qualified institutes, i.e. the Nederlands Meetinstituut (NMi, Dutch Measurement Institute), and the Belgian StudieCentrum voor Kernenergie (SCK•CEN, Belgian Nuclear Research Centre). The testing and control of radiation measuring equipment is performed on a regular basis which may be daily, such as in the case of germanium detectors, up to yearly, e.g. tritium samplers.

Archiving and Reporting
Relevant monitoring data are registered during the campaign activities on the appropriate forms and relevant values of dose rates and air contamination are preserved during the campaign activities, i.e. receipt, processing, and storage of radioactive waste in the HABOG.

All monitoring data of the on-line measuring systems are preserved during one month. In addition, each device stores internally mean 1-minute, 10-minutes, 1-hour, and 24-hours values. The monitoring data and data reports will be preserved for at least 1 year. Data measured on the waste canisters itself will be preserved for at least 100 years. Data that need to be stored longer than 15 years are printed on long-lasting paper with dedicated ink. The printed data sheets are stored in a conditioned room. In addition, the data are stored digitally as TIFF image files within the ZYLAB archive system.

The results of the stack samplings of tritium and ^{14}C are registered and archived for the determination of the yearly emissions to the atmosphere and surface water. Emission data are registered and reported in the quarterly reports. Most monitored data in the HABOG facility as well as in the other facilities at the COVRA site are available to the public through the quarterly and yearly reports.

Protocols in case of deviations
Deviations from the background values may occur as a result of contamination or incidents. In those cases COVRA protocols come into operation to mitigate the radiological consequences. Apart from the normal procedures to comply with the safety of the persons involved and to decontaminate rooms, surfaces and objects, legislation requires that the incidents, including all relevant details, are reported and archived.

8.3.5.3 Spatial radiation monitoring at COVRA

In addition to the continuous and periodical routine monitoring activities, COVRA also hosts two innovative monitoring projects for the spatial characterization of the radiation in the storage building and the contents of radioactive waste containers:

- Characterization of hot spots in stacked waste containers (LILW)
- Characterization of activity profiles inside waste containers (HLW)

Both projects are joint effort between COVRA and NRG, and are described in somewhat more detail in the subsequent paragraphs.

Characterization of hot spots in stacked waste containers
Conditioned low and intermediate level radioactive waste is stored in a separate building of the COVRA facilities, the “LOG”, “Laag- en middelactief afval Opslag Gebouw”, the low and intermediate level waste storage building. In this facility the radioactive waste containers are stacked along the walls. To minimize the radiation exposure of the employers, an inventive strategy is used for the spatial

arrangement of the containers: the containers with the highest activity are surrounded as much as possible by containers with lower activities in order to maximize the shielding effect and to provide a relatively low radiation level in-between the stacked containers, i.e. in the inspection corridors.

To validate the existing waste storage strategy and procedures applied it was considered relevant to measure the spatial distribution of the radiation exposure inside the storage buildings, as well as in the stacks of waste vessels in the LILW storage facility, the LOG. In a joint effort of COVRA and NRG a non-destructive assay project was initiated to determine the radiation exposure distribution in order to validate the applied strategy and procedures in the LOG [Van Velzen, 2009].

The principle of the developed fast characterization technique is the collection of radiation data by sensors that are moving continuously along the surface of the large stacks of waste containers. Simultaneously the location of the sensors relative to the surface of the waste item is recorded. In this way measured radiation data can be linked to the exact location of the waste item and the dose rate emitted from the waste volumes can be calculated. This novel non-destructive assay method is called INDSS-R (acronym for INDoor Survey System – Radiation). The prototype of the INDSS-R system is shown in Figure 8-8.

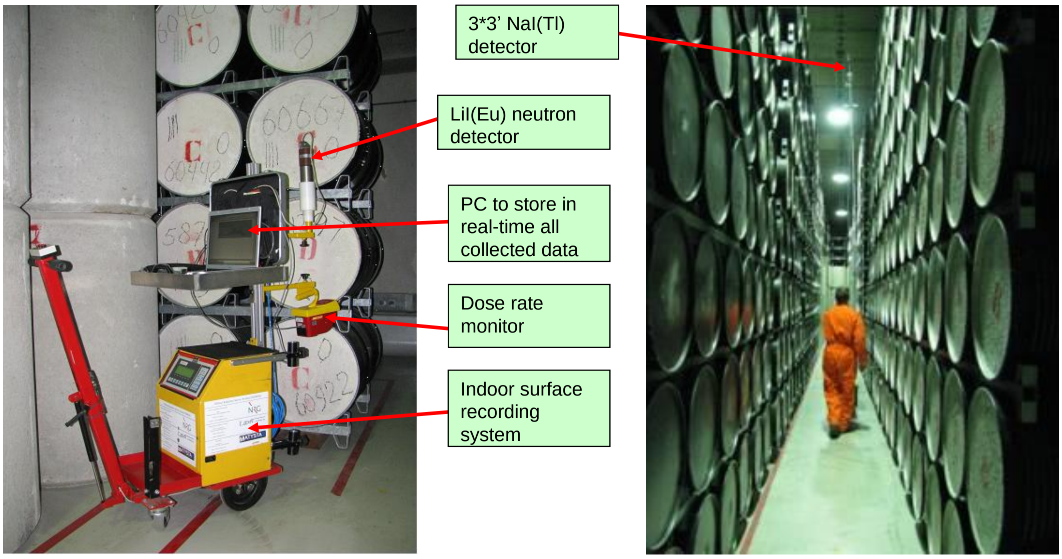


Figure 8-8: Picture of the INDSS-R system next to a stack of vessels (left) end the system in operation (right)

In December 2004 the first spatial dose rate measurements were performed in LILW storage module TL120 of the COVRA site. With this method the following spatial radiation data have been collected:

- Dose rate.
- Nuclide specific photon flux. Of each detected photon the energy and its detection time is stored. The software to collect and analyze the data has the possibility to select 20 regions of interest and replay the data. The photon flux is measured by means of a 3*3" NaI(Tl) detector coupled to an ORTEC Digibase.
- Thermal neutron flux data. The thermal neutron flux has been measured with a LiI(Eu) coupled to an ORTEC Digibase.

The analysis procedure for the spatial data from the interim waste storage facility is as follows:

1. Review the collected location and radiological data and adjust these data where needed.
2. Link net radiological data to their unique location data.
3. Perform *data significance calculations (DSC)* to determine data which differ significantly -positively or negatively- from the mean value of the collected data set.
4. Present net data and DSC data in iso-plots.

An example of the obtained results is depicted in Figure 8-9, showing the net dose rate plots (top) and DSC dose rate iso-plots (bottom) collected in the storage module TL120 (*x*-axis width = 40 m and *y*-axis length = 70 m) at three different points in time. The dose rate is collected with a sampling frequency of one per second and at an average continuous speed of the module of 0.6 m/s. This frequency results in one collected dose rate data point for an average surface of about 0.5 m^2. Figure 8-9 clearly shows the location of the hot spots (red and yellow) in the stacked vessels.

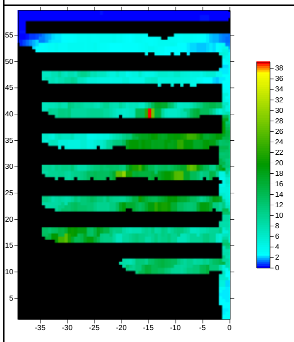
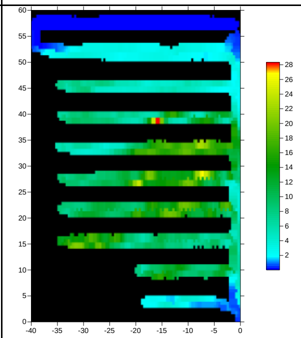
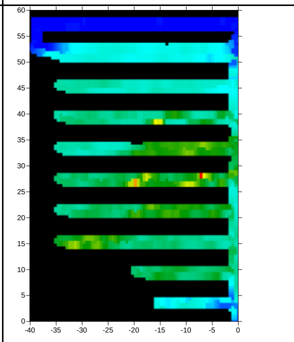
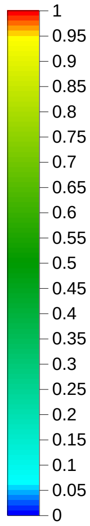
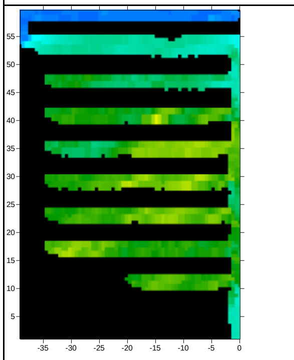
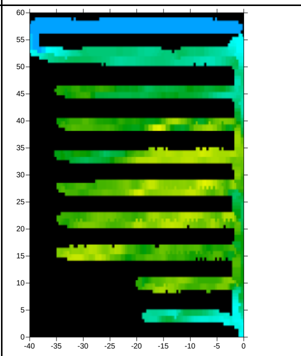
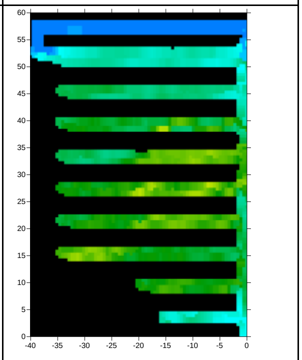
Series 2004 Height 4.50 m Max 39 µSv/h	Series 2006 Height 4.24 m Max 28.5 µSv/h	Series 2008 Height 4.53 m Max 20.7 µSv/h	Color bar
			
DSC iso-plots			
			

Figure 8-9: Iso-plots of collected dose rates at a height of about 4.5 m normalised by the maximum dose rate in the COVRA storage module TL120

The efficacy of the LILW storage strategy in the LOG-building and procedures to "minimize the dose to the public at the fence and to employees during inspections of the stored waste in the facility" can be assessed by interpretation of Figure 8-9. This figure shows that a large area (an estimated 400 m^2 which equals about 15% of the total surface of the module) has a dose rate below the ceiling of storage module TL120 of more than 8 µSv/h with local maxima of about 39 µSv/h in 2004 and 21 µSv/h in 2008. Such a large elevated area contributes to the sky-shine and increases the dose rate at the border of the COVRA site. Based on the results of the first spatial dose rate measurement in 2004 in storage module TL120 COVRA modified the design and increased shielding properties of the ceiling of their planned fourth LILW storage module TL140. That module was commissioned mid 2007.

Further, it was concluded that the direct radiation through the wall of the storage module is less than 2 µSv/h. The INDSS-R system provided sufficient insight for the health physics department of COVRA with regard to dose rate distributions that it was decided to stop the weekly radiological control routine of LOG storage module TL120. This lead to a reduction in the dose rate for the involved personnel of about 10 µSv/week.

Characterisation of activity profiles inside waste containers

In a joint effort of COVRA and NRG a non-destructive assay (NDA) system has been developed and tested which can replace emission computer tomography (ECT) and transmission computer tomography (TCT) for the routine characterization of decayed radioactive waste 220 liters drums.

For that purpose the existing fast scan system described above has been extended with a portable transmission system that fulfils the requirements of fast scan measurements. By the application of a gamma source and a detector system, transmission data can be obtained for a 220 liters waste drum, containing different super compacted waste forms. The transmission data, determined at different angles of the waste drum, can be processed to establish information about the contents of the drum. The data processing is done by means of the analysis program HOLIS (HOt-spot Localization using Intelligent Software) developed by NRG. HOLIS is able to calculate the total specific nuclide activity within the predefined requirement of 10% precision, the specific activities of hot-spots and their location inside the drum, and the uniform activity of the drum [Van Velzen, 2007].

In Figure 8-10 (left) an example of a 220-liter drum is shown, which is representative of the waste drums stored in the COVRA facilities. This particular drum contains super compacted plastic containers as well as compacted 100 liters drums. Data collection is done by moving the gamma source and the detector along the waste drum and simultaneously measuring the transmission through the waste drum at every subsequent location.

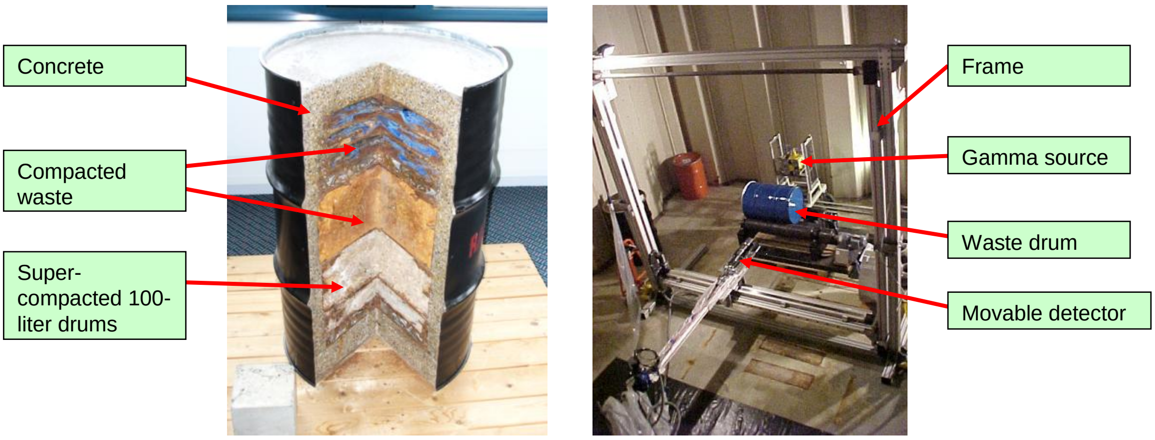


Figure 8-10: Left: a cut through of a 220 liters drum containing different super compacted 100 liters drums (lower part). Right: the arrangement of the non-destructive assay system.

By analyzing the collected transmission data by means of the HOLIS programme the location of any present hot spots inside the drum can be determined (see also Figure 8-11).

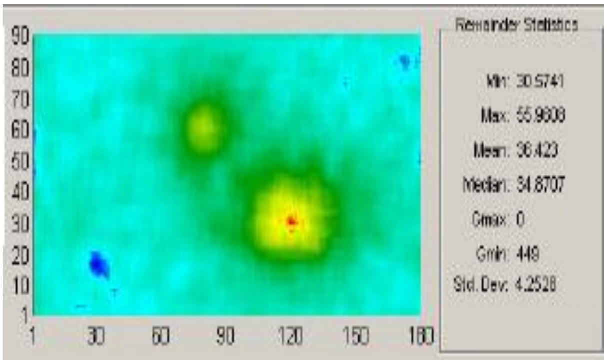


Figure 8-11 Iso-plot of a cross-cut of a 220 liters drum showing two hot spots

At present the hardware/software system allows 1800 gamma spectra to be collected in 1800 seconds. The next step in the development of the system will be to enable a collection of a maximum of 18000 gamma spectra in 1800 seconds. In practice this will mean that for the radiological characterization of 220 liters drums for every square centimetre of the outer surface of the drum a gamma spectrum can be determined.

Further development of the mechanical system is still needed to be able to operate the system in routine circumstances. The developed NDA system is still a prototype system and is operated and tested in a R&D environment. Therefore the system has also to be tested under real working conditions that apply in a waste storage facility. These tests will also help to determine if the system fulfils all regulations regarding to occupational health and safety.

The existing version of the analysis software HOLIS has been tested manually in an R&D environment by software developers and specialists. In routine operations however HOLIS has to run automatically and has to be user-friendly enough to be accessible for the operators at the COVRA. This aspect requires additional development of the software.

8.3.6 Disposal concept – definition of upstream disposal process management decisions

Such decisions might be pertaining for example to (i) the need to provide for retrieval or not, (ii) the need to include a well defined, step wise decision process for progressive construction, operation and closure, (iii) thermal management (imposing temperature limits)…

As already mentioned, no final decisions have been made in the Netherlands or are foreseen in the near future regarding geological disposal of radioactive waste. The development of national policy on long-term management of radioactive waste will be undertaken in a stepwise manner. A key element in this process is the aspect of retrievability, which is part of Dutch policy since 1993 [Dutch Government, 1993] and in-line with a collective opinion of the Radioactive Waste Management Committee of the NEA [NEA, 1995].

In a technical document produced within the CORA program considerations were developed concerning the role of monitoring in a retrievability concept [van Gemert, 2000]. Such a role can be twofold: whatever the reasons for monitoring, if the monitoring data indicate a failure to reach the required standards, or indicate that the repository systems behave in an adverse way, the presence of monitoring data can form the basis for judging the necessity of corrective action. The ultimate corrective action would be the retrieval (of parts) of the waste. From this viewpoint retrievability is seen as secondary to monitoring.

On the other hand, there are reasons for providing retrievability that are unconnected to monitoring on first sight, for example to provide options for future generations as discussed in the previous section. Here retrievability, rather that monitoring, is the primary issue and monitoring data may be consulted to judge if and how the retrieval of waste canister can be carried out safely. From this viewpoint there appear to be three ways in which monitoring can serve retrievability:

- First, by monitoring a range of parameters relevant to package integrity and waste accessibility, monitoring may be used to establish that the waste packages are retrievable, as well as how easy or complicated actual retrieval might be.
- Second, monitoring might be used to provide data to make it possible to take a decision to postpone closure of cells, depositing tunnels, access tunnels and access shafts, depending on the current phase of the disposal.
- Third, monitoring may be used to demonstrate that the systems installed to allow reversibility of operations remain fit for that purpose.

8.4 Decisional process

As described in the previous sections, deep geological disposal is the Netherlands is still in a conceptual phase. No specific decisions on monitoring are made or will be made in the near future. However, a separate technical document within the CORA program mentioned some aspects in relation to the decisional process in the case of retrievable disposal [van Gemert, 2000].

The full range of monitoring activities that will comprise the monitoring programme in the different phases of development and implementation of the repository is clearly much broader than those that would be necessary from considerations related to retrievability. Monitoring activities are related to retrievability considerations in the following ways:

- Some monitoring activities will provide information as to how (and with how much ease) the waste packages could be retrieved should such a decision be taken to do so. Such a decision could be taken on the basis of information relating to developments in the repository (see next bullet point) or could be related to other developments (e.g. the availability of new waste management technologies). This information would cover the accessibility of the waste and its confinement packages;
- Results (i.e. measurements) from some monitoring activities could conceivably trigger a decision to retrieve the waste - for example, if the measurements indicated that the repository was not performing as expected;
- Results (i.e. measurements) from some monitoring activities could contribute to an enhanced confidence in the behaviour of the repository system and hence facilitate a decision to progress to the next stage of the repository implementation. An example would be a decision to move to a phase in which a future retrieval of the waste becomes more difficult.

The following events and processes would be important for the decision to retrieve the waste [van Gemert, 2000]:

- Due to high temperature or chemical reactions of the waste matrix diffuse nuclides may be mobilised;

- Due to high temperature, radiation or water intrusion the backfill material and buffer material may change chemically or physically and lose its characteristic of being easily removable;
- The support construction might deform under the pressure, to such an extent that the retrieval machine can't work;
- Due to flooding or collapses the facility may become inaccessible.

These events and processes would require monitoring of the following parameters:
- Temperature of all components of the disposal cell;
- Water content of the disposal cell;
- Deformation of the disposal cell's liner.

Monitoring of these parameters is in compliance with NRG's present interest in the MoDeRn work programme: it is important to deal with the question of how to handle discrepancies between expected and unexpected repository evolution, the possible impact on needed technical action and on the wider acceptance and confidence in the disposal process, and on how this might influence the decision making in either a staged disposal approach, or a possible retrieval of already emplaced waste canisters.

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9. Finnish national context (Posiva)

Posiva is the nuclear waste management organisation in Finland responsible for the disposal of spent fuel from the Loviisa and Olkiluoto nuclear power stations. This means research into geologic disposal and later the construction, operation and eventual backfilling and closure of the disposal facility. In 2001 the Parliament ratified the Government's favourable Decision in Principle (DiP) on Posiva's application to locate the repository at Olkiluoto. Spent fuel from the Loviisa and Olkiluoto nuclear power reactors is planned to be disposed of in a KBS-3 type repository to be constructed at a depth of between 400 and 600 m in the crystalline bedrock.

Pursuant to the guidelines given by the Ministry of Trade and Industry (KTM) (which is changed to the Ministry of Employment and the Economy January 2008) Posiva aims at submission of the application of the construction license for the disposal facility by the end of the year 2012. Current plans and activities to attain this goal are described in Posiva's Programme for Research, Development and Technical Design (RTD) for 2007–2009 (Posiva 2006). Planning of the new RTD for years 2010-2012 is now ongoing and it will be published end of the year 2009.

Olkiluoto is a large island (~ 10 km2) on the Baltic Sea coast and separated from the mainland by a narrow strait. The Olkiluoto nuclear power plant, with two reactors in operation and a third one under construction, and the VLJ repository for low and intermediate waste are located in the western part of the island. The repository for spent fuel will be constructed in the central part of the island (Figure 9-1). The suitability of Olkiluoto as a location for a spent fuel repository has been investigated over a period of fifteen years by means of ground- and air-based methods and from shallow and deep (300 – 1000 m) boreholes.

At the moment Posiva is constructing an underground rock characterization facility, "ONKALO" at Olkiluoto. The investigations in the ONKALO aim at further characterisation of the bedrock properties and groundwater characteristics and to help support decisions for selecting the most suitable locations for the first deposition tunnels and disposal holes for spent fuel canisters. Tests and demonstrations of repository technologies will also be carried out in the ONKALO. When completed, the underground parts of the ONKALO will consist of a system of exploratory tunnels accessed by an inclined tunnel, or ramp, and shafts. The characterisation level, which will be reached in early 2010, will be located at a depth of about 420 m.

Demonstrations and tests of repository technologies will be mainly carried out at the characterisation level, but characterisation of the rock mass is already taking place using pilot holes drilled along parts of the tunnel axis, prior to its excavation, by tunnel mapping and by monitoring the impact of construction. Surface based-investigations, including the drilling of additional deep boreholes and the excavation of further investigation trenches, are also taking place.

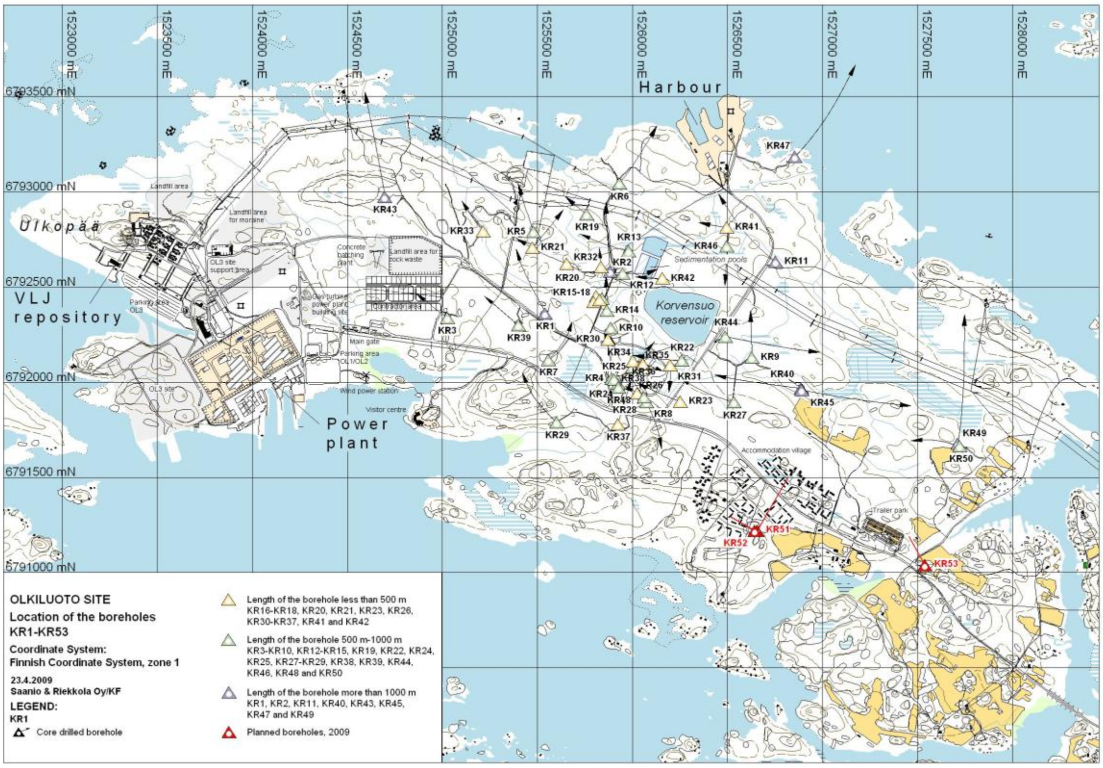

Figure 9-1. Deep boreholes at Olkiluoto. The size of the grid squares is 500 x 500 m.

A programme of monitoring has been launched as part of the investigations and to follow the changes occurring within the site due to the construction. The programme for monitoring of impacts due to construction and operation of ONKALO started in the year 2004, one year before the actual construction work. Rock mechanics, hydrology, hydrogeochemistry, the surface environment and the use of foreign materials (e.g. cement and explosives used in ONKALO) are included in the monitoring programme (Posiva 2003a).

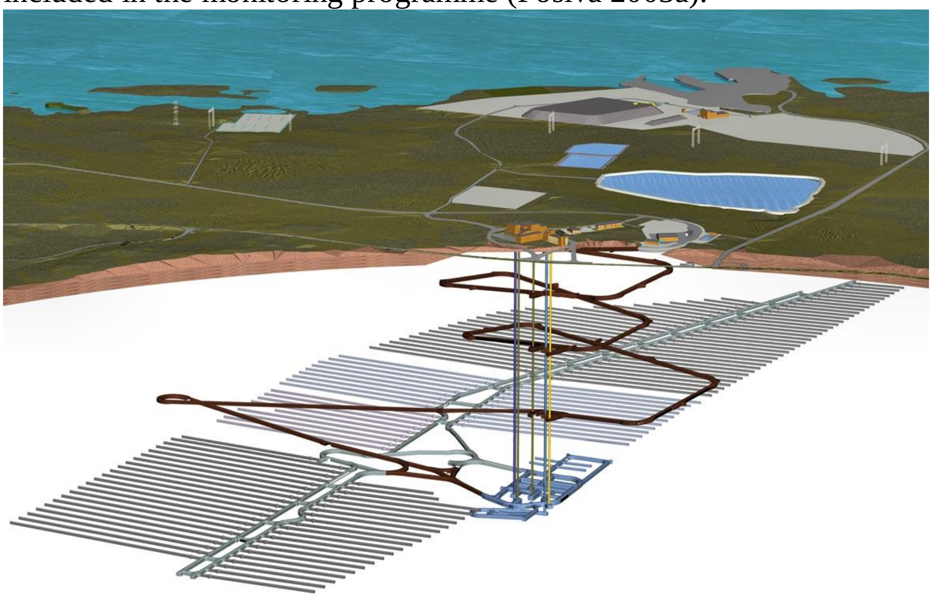

Figure 9-2. General illustration of disposal facility complex, including above ground and underground facilities.

9.1 Site description

The activities related to ONKALO, as well as, other characterisation activities at Olkiluoto, produce a substantial amount of data. These data need to be incorporated into models of the site to be used as input, both for the further construction of ONKALO and for use in subsequent safety analyses and licence applications.

Several site syntheses have been compiled for the Olkiluoto site. The information available before ONKALO construction is summarised in Anttila et al. (1999) and the Baseline report (Posiva 2003b). As the construction of ONKALO started, the Olkiluoto Modelling Task Force (OMTF) was established for planning and integrating the results of the investigations and for undertaking the modelling work of the various disciplines and to develop site descriptive models of the Olkiluoto site, as well as predicting and evaluating the disturbance created by the construction of the ONKALO ramp and the characterisation tunnels. The main product of the modelling is the site descriptive model (SDM), which describes the geometry, properties of the bedrock and the water, and the interacting processes and mechanisms that are relevant for understanding the evolution of the site to the present day and the potential for future radionuclide migration. The SDM is divided into the following disciplines: surface system, geology, rock mechanics, hydrogeology, hydrogeochemistry and transport properties. The resulting (geo)syntheses are reported in a series of Site Reports (Posiva 2005 and Andersson et al. 2007) , the newest revision (Posiva 2009) will be published in spring 2009.

Based on the presented site syntheses described above, the present site understanding can be summarised as follows:

The bedrock at Olkiluoto belongs to the Fennoscandian domain of Southern Finland and it comprises a range of high-grade metamorphic rocks and igneous rocks. The metamorphic rocks include various migmatitic gneisses and homogeneous, banded or only weakly migmatised gneisses. This results in relatively low and varying thermal conductivity, compared to typical values of the Fennoscandian shield. The uniaxial compressive strength is also varying in most of the rock types and it shows a quite large spread. Rock stresses are comparable to typical values of the Fennoscandian shield but the orientation of the major stress field at planned repository level is somewhat uncertain. Stress/strength –ratio of the rock is such that limited rock damages may occur around the excavated rooms at the planned repository depth. The bedrock has been affected by ductile deformation, which is reflected by significant foliation. This results in anisotropy of thermal and rock mechanics properties.

The fault zones at Olkiluoto are mainly SE-dipping thrust faults. In addition, NE-SW striking strike-slip faults are also common. Away from the near surface part of the rock, hydraulically connected transmissive fractures, especially those with transmissivity values higher than 10 8 m2/s are concentrated mainly in three regions of the SE dipping faults. These regions are modelled as hydrogeological zones (HZ). Connected fractures with lower transmissivity occur outside these zones, but they also tend to form clusters.

Meteoric water is found only at shallow depths, in the uppermost tens of metres, brackish groundwater, with salinity up to 10 g/l dominates at depths between 30 m and about 400 m. Saline groundwaters (salinity > 10 g/l) dominate at still greater depths. The hydrogeochemical conditions in the bedrock and their distribution are the result of progressive mixing and reactions between various initial water types, which represent some of the major events at the site during its geological history. Sulphide is enriched in the depth interface, where major SO4 disappears and CH4 correspondingly starts to increase notably. Redox conditions at Olkiluoto have been considered to be anoxic except in shallow infiltrating groundwater in few cases. This interpretation is also supported by the observations of scarce iron oxyhydroxides from fracture surfaces beneath the uppermost ten metres. Pyrite and other iron sulphides are instead common in fractures throughout the investigated depth zone indicating strong lithological buffer against oxic waters during geological time scales. In this zone, SO4-rich groundwater is mixed with dissolved methane to result, in places (250 – 350 m), in exceptionally high levels of dissolved sulphide as a microbially mediated reaction product.

Prediction/Outcome studies are part of the site description. These studies aim to assess how the increased knowledge and experience gained from the construction of the ONKALO has enhanced the level of site understanding and the predictive capability of the modelling teams, as well as providing input and testing of the developing Rock Suitability Criteria (RSC). Predictions of geological properties, rock stability and both hydrogeological and hydrogeochemical impacts of ONKALO construction are made. The latest site description (Posiva 2009) concludes that there is a good to fair agreement with predictions based on both the pilot holes and the previous site model (v. 2006, Andersson et al. 2007) and outcome for lithology, ductile deformation and intersections with brittle deformation zones. The observed differences between the predictions and the outcome are mainly due to resolution of the models and observed data, e.g. different resolution of lithologcal description in pilot holes and in tunnels, small scale variation of foliation not captured in the models, smaller scale deformation zones observed in the tunnel are not included in the site scale models and most notably, a difference in fracture frequency mapped from the pilot hole compared to tunnel. The observed rock damages occur mainly on tunnel sections predicted to have higher probability of the rock spalling.

Tunnel inflow, drawdown of the groundwater table and changes in groundwater composition (salinity) have also been predicted. The tunnel inflow is controlled by grouting and is below 1 l/min/100 m. The tunnel inflow is typically estimated to be higher based on the observations from the surface based holes than from the tunnel holes or actually observed. The drawdown is minimal close to surface, but the construction of ONKALO has affected the hydraulic head of some deeply located packed off sections in some drillholes especially close to ONKALO. These sections are connected to ONKALO through major hydraulic zones. There is a good match of predictions and observations of inflow and drawdown. Upconing of deep saline groundwater is predicted (from 21 g/l up to 30 g/l at 500 m level), but there is not yet data available to judge the validity of these predictions.

The site description also includes an assessment of uncertainty and confidence in the description and addresses development in relation to the main issues identified in the previous version, with focus on those issues judged to be most important for the safety case.

The general properties of the site, like rock mechanics and thermal properties, variation of the groundwater salinity, the deformation zones and major hydrogeological zones provided by the Site Descriptive Model will be considered when locating the repository. A more detailed scale description of the rock volume surrounding ONKALO has also been produced (Kemppainen et al. 2007). This ONKALO model describes e.g. the observed location of the deformation zones in the tunnel and tunnel cross cutting features.

9.2 Waste disposal package design and functions

According to two Decisions-in-Principle of the government, the amount of spent nuclear fuel from the nuclear power plants in operation and from the Olkiluoto 3 unit (under construction), is permitted to be disposed of in Olkiluoto bedrock. The design of the disposal facility is presently based on the KBS-3V concept (vertical disposal), but the feasibility of a horizontal variant (KBS-3H) is being studied. Long-term safety in the concept is based on the multi-barrier principle i.e. several release barriers, which back up one another so that deficient performance of one barrier does not jeopardize the long-term safety of disposal. The release barriers include: the canister, the bentonite buffer and the disposal tunnel backfill, as well as the host rock around the repository. The surrounding bedrock and the central and access tunnel backfill provide for additional retardation, retention, and dilution.

The disposal facility consists of an encapsulation plant, other buildings and surface structures serving the facility, and a deep repository. The construction works needed for the disposal facility start after the construction licence has been obtained. The application will be submitted to the government in the year 2012. The operation of the facility starts in 2020 after the operating license has been granted.

Spent nuclear fuel from the interim stores is encapsulated into canisters in an encapsulation plant and then transferred into the repository through a shaft. According to the current design, the repository layout is based on a one-storey layout alternative at the level of -420 m. The repository is accessed through a tunnel and shafts. The tight and corrosion resistant canisters are installed into deposition holes, which are bored in the floor of the disposal tunnels. The canisters are enveloped with compacted bentonite blocks, which swell up as they absorb water. More disposal and central tunnels are excavated as disposal proceeds.

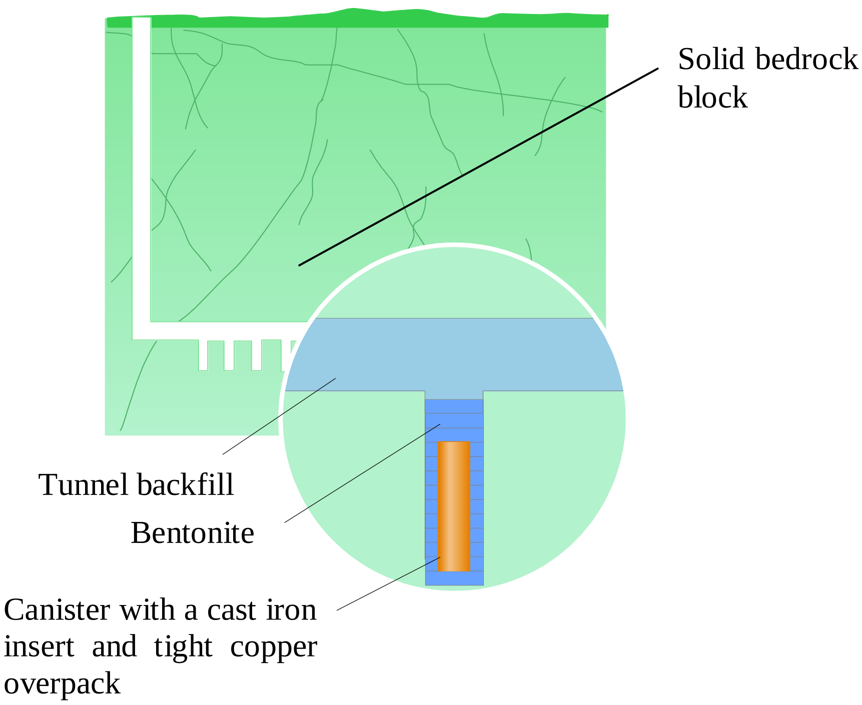

Figure 9-3. Disposal Concept Based on Multiple Engineered Barriers. The different engineered barriers complement each other.

According to the disposal concept, the spent fuel assemblies are installed and enclosed in the cast iron insert of the copper canister. The copper canister lid and the overpack are sealed tightly, so that groundwater flowing in the bedrock cannot come into contact with the cast iron insert or the spent fuel. This ensures isolation of the spent fuel and prevents release of radionuclides to the groundwater and further to the geosphere and to the biosphere. Individual copper canisters are emplaced in deposition holes at the bottom of the disposal tunnels excavated in the solid bedrock at a depth of about 400 metres.

Each vertical deposition hole is lined with bentonite, which is swelling natural clay material that serves as a buffer material between the host rock and the canister. Once the canister has been emplaced in the deposition hole lined with bentonite, an additional layer of bentonite buffer is placed on top of the canister in order to fill the hole up to the level of the disposal tunnel floor. The purpose of the bentonite, after it has become saturated, is to stop any flow of groundwater around the canister, to conduct the heat produced by the spent fuel from the canister to the rock, to provide sufficient permeability to gases that are formed inside the canister mainly as a result of corrosion and, simultaneously, to absorb any radionuclides released from the canister. Bentonite also provides mechanical support to keep it in its original position. Being more elastic than the canister and the bedrock, bentonite protects the canister against minor rock movements. The near-field bedrock surrounding the deposition hole protects the canister against unfavourable disposal conditions and the rest of the surrounding bedrock, as the last release barrier, retards and dilutes any release of radionuclides from the canister.

The disposal tunnels are sealed with compacted clay material to ensure that the bentonite buffer stays in the deposition hole as it swells and prevents the disposal tunnels from becoming new flow paths for groundwater. The backfill will also prevent unintentional or intentional intrusion into the repository. (Tanskanen 2007)

9.3 Disposal schedule

<u>Key milestones and phases in design and implementation of final disposal facility up till 2020</u>
The development of final disposal was started in the early 1980s soon after the commissioning of the nuclear power plants. The phase before the year 2000 can be referred to as the site characterisation and selection phase. Olkiluoto in the municipality of Eurajoki was selected from among the four site alternatives as the disposal site in 2000.

The period started after the Decision-in-Principle consists of investigations for site confirmation, research into long-term safety of the disposal concept and development of a Olkiluoto-specific design of the repository. This period is strongly affected by the construction work of ONKALO and the underground characterisation that is being carried out in ONKALO. The purpose of these underground investigations is to obtain adequate knowledge of the site in order to achieve the maturity needed for submitting an application for the construction licence. The application for the construction licence will be submitted to the Government in 2012. The Ministry of Trade and Industry will review the status of Posiva's programme as regards the submittal of the construction licence application on the basis of the documentation that Posiva will report in 2009. The application for the construction licence will include the documentation reported in 2012, the content of which will be specified in more detail in connection with the preparation of the 2009 RTD programme and the facility description.

This preliminary safety assessment report (PSAR) of the technical solutions presented in the facility plans, which is required for the construction licence application, will be drawn up as a part of Posiva's future design stages, the outline planning stage and the main drawings stage.

The detailed realisation plans for the disposal facility will be developed and the surface buildings and underground rooms constructed during the period 2012-2020. The target year for the facility test run is 2019. In the pilot test the disposal facility is operated with non-active material. An application for an operation licence for the facility is to be submitted to the Government by the end of 2018. The application is preceded by the final safety analysis report, FSAR, which is drawn up as part of the realisation stage and implementation. Disposal operation is planned to start in 2020.

The overall schedule 2006 – 2020 for the design and implementation of the final disposal facility is shown in Figure 9-4. (Tanskanen 2007)

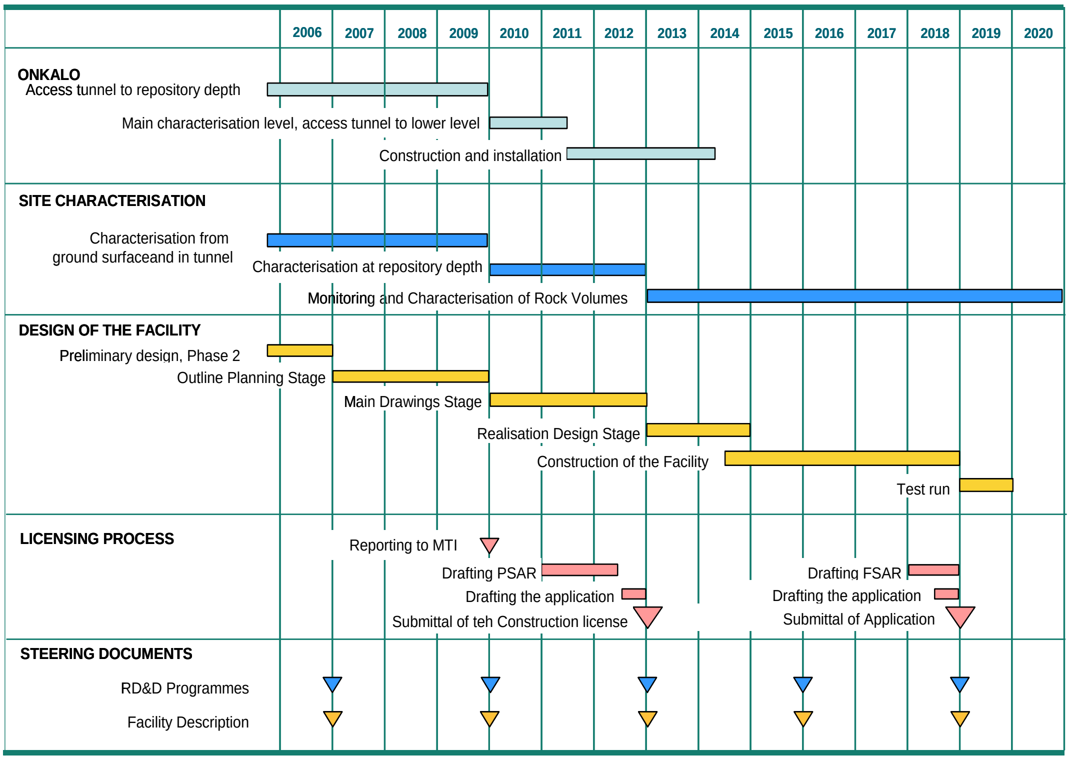

Figure 9-4. Project schedule 2006-2020.

<u>Disposal operation schedule</u>

The facility design is based on an operating life of 50 years for the Loviisa reactors and 60 years for the Olkiluoto reactors. In other words, the operation of LO1-2 plants would stop around 2030, the operation of OL1-2 plants around 2040 and the operation of the OL3 plant around 2070.

The main programme is targeting of is at starting the disposal operations in 2020. Another planning assumption is that each of the fuel assemblies unloaded from the reactor has been cooled down an average of 40 years to reduce the repository volume requirements. The third and a very definitive edge condition is that the temperature of bentonite may not exceed 100oC in the repository.

Table 9-1 as well as Figure 9-5 show the disposal schedule based on calculations. It covers both the effect of the existing power plant units and estimates for the new power plant unit under construction.

Table 9-1. Disposal operation schedules based on maximum permitted decay heat power values for the different canister types at the time of disposal.

Fuel source	Max. burnup (MWd / kgU)	Num-ber of assembli es/ canis-ter	Start of dispo-sal	Dispo-sal period (a)	Min as-sembly cooling time (a)	Amount of U (tU)	No. of canis-ters	Encap-sulat-ion rate (pcs/a)
OL1-2	50	12	2020	53	20	2533	1210	22,8
Lo1-2	45	12	2020	37	25	1018	698	18,9
OL3	50	4	appr. 2067	45	38	1980	932	20,7

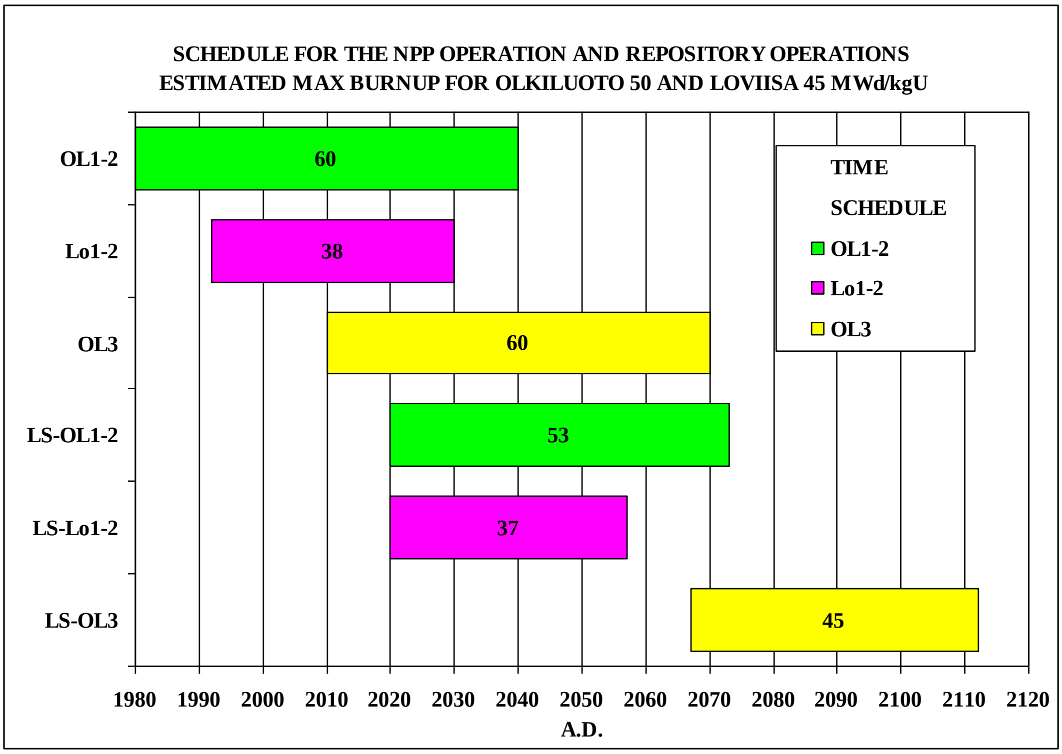

Figure 9-5. Planned operating lives of Finnish nuclear power plant units and resulting spent fuel disposal schedules. (LS means disposal)

The canister disposal rate varies during the operating phase. During the first part of the disposal period, in years 2020 – 2057, the average annual disposal rate is about 40 OL1-2 and Lo1-2 fuel canisters. After that, up to year 2067, only about 25 OL1-2 fuel canisters are disposed of annually. After the year 2067, the disposal of OL3 fuel canisters starts. In years 2067 - 2073 some 45 OL1-2 and OL3 fuel canisters on average are disposed of annually. When the disposal of OL1-2 canisters ends in 2073, about 20 OL3 fuel canisters are disposed of annually up till 2112 (Saanio et al. 2006).

The normal disposal rate, about 40 canisters a year, is based on employing one disposal tunnel at a time. In one year less than two disposal tunnels are filled.

If needed, the disposal rate can easily be multiplied by employing two or even four disposal tunnels in parallel. This would be rational if the generation of spent fuel ceased. In that case the existing fuel should be disposed of as fast as possible. The maximum design encapsulation capacity of the disposal facility is 100 canisters per year. (Tanskanen 2007)

9.4 Legal and regulatory framework

<u>The construction and operation phases</u>

The new Government Decree on general safety requirements for the disposal of spent fuel stipulates that (STUK 2008) (editor's translation):

“The design, excavation, other construction and closure of the underground facility shall be implemented in the best manner with regard to retaining the characteristics of the host rock that are important to long-term safety”.

In addition to the general safety requirements to keep the disturbance to the host rock to the minimum, the Environmental Impact Assessment (EIA) legislation sets general requirements for monitoring. The existing guidelines for an EIA state that the implementer must formulate a programme for monitoring the potential environmental impact. The Ministry of Trade and Industry stated that the principles defining the monitoring programme should be clarified before the application for the construction licence for the repository is submitted (KTM 1999).

The Government Decree on general safety requirements for the disposal of the nuclear waste (STUK 2008) was published at end of the year 2008 and replaced an earlier Government Decision on safety requirements. In these updated requirements it was now stated that (editor's translation):

“…in the operation phase a research and monitoring programme has to be implemented to ensure the long-term performance of the engineered barrier systems.”

Updated Regulatory Guides (YVL Guides) issued by the Radiation and Nuclear Safety Authority are expected to be published during 2009. According to the draft version of the document (editor's translation):

"During the construction and operation of the nuclear waste repository there has to be a research, testing and monitoring programme that ensures the applicability of the constructed facilities to the final disposal of nuclear waste, determines the bedrock characteristics that are important to the safety and ensures the long-term capacities of the barriers. This programme must include at least:

- *an explanation of the characteristics of the bedrock blocks designed for construction*
- *monitoring of the rock stress, movements and deformations of the bedrock surrounding the disposal facilities*
- *monitoring of the hydrogeology in the bedrock surrounding the disposal facilities*
- *monitoring of the hydrogeochemistry at the disposal site and*
- *monitoring of the behaviour of the technical barriers."*

The implications of these new requirements about monitoring of the behaviour of the technical barriers are under consideration at Posiva.

<u>The post-closure phase</u>

The possibility of post-closure monitoring is mentioned in the Nuclear Energy Law. The responsibility for monitoring would rest with the State after the waste generators have paid a lump sum for the costs of such activities.

Also in YVL Guides is mentioned the post-closure phase. According to the YVL Guide 8.4, issued by the Radiation and Nuclear Safety Authority (STUK 2001):

"...facilitation of retrievability or potential post-closure surveillance activities shall not impair the long-term safety."

<u>Other requirements for monitoring</u>

Other official requirements for monitoring are concerned with the safety of underground work or with surveillance of the surface environment. In addition, the safeguards obligations related to the Non-proliferation Treaty may impose additional requirements on monitoring. Such aspects of monitoring will be taken into account in the technical planning and design work for the ONKALO.

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10.Czech national context (Rawra)

The Czech National Context is based on a primary assumption that the Czech Republic has undertaken the responsibility for safe radioactive waste management. For this purpose a state organization – Radioactive Waste Repository Authority (RAWRA) - was established under the provision of Atomic Act 18/1997, on the peaceful uses of nuclear energy and ionising radiation.
RAWRA´s mission is to ensure a safe disposal of the existing radioactive waste, to develop a deep geological repository for the high level waste and to support research activities in this field.
The activities of the RAWRA are financed from nuclear account the income of which comprises mainly from payment from waste generators.

According to the Atomic Act 18/1997 spent nuclear fuel is not considered as a waste until its owner (nuclear energy producer and other) or State Office for Nuclear Safety (SUJB) as a regulatory body declares it. For that reason the nuclear energy producer operates an interim storage of SNF.

Since 2000 when RAWRA in compliance with relevant licences granted by the SUJB and, with permits and licences issued by the Czech Mining Office has undertaken responsibility for all the existing repositories, three LILW repositories have been operating. The repository of a surface type, situated in the NPP Dukovany area is assigned for the waste generated during the nuclear power plant operation. The waste containing natural radionuclides are disposed of in the Bratrství repository, adapted from a former uranium mine. The waste generated in industry and in research and medicinal applications of ionising radiation is disposed of in an abandoned limestone mine Richard. Both the repositories Bratrství and Richard are near-surface type of repositories. LILW repositories are operated under inspection of a regulatory body – the State Office for Nuclear Safety (SUJB). The radiation monitoring of these repositories is carried out under legislative derived from ICRP (The International Commission on Radiological Protection) and IAEA standards and requirements.

The Concept of the Radioactive Waste and Spent Nuclear Fuel Management in the Czech Republic is a government document appointing the milestones and future plans in the field of nuclear energetic and waste management. According to the Concept, the long-term storage and following disposal in geological formation is considered a basic national strategy. In addition, the progress of separation (partitioning) and transmutation technologies is monitored and supported. No retrievability is envisaged in the Czech concept.

In compliance with the Concept the main milestones of DGR development are as follows:

2015	To select sites with proper geological conditions taking into account local developments at proposed sites. After evaluation of relevant results include two sites into land use plans (main and reserve one) for deep geological repository
2025	On the basis of geological work performed and complex data analysis confirm the suitability of one site for a geological repository
2030	To prepare the necessary documentation for construction of an underground research laboratory and performance of long term experiments for confirmation of safety of deep geological repository

2050	Deep geological repository construction
2065	Operation of deep geological repository

The program of the deep geological repository development has been started in 90´s. The candidate site selection process commenced with the assessment of a suitability of various rock formations and has been followed by a geological research at potentially suitable sites. Six localities were selected for the further geological survey.

In view of local public pressure, work was subsequently suspended; the Government, by means of Decision No. 550 of 2 June 2004, effectively suspended geological survey works until 2009 at all the candidate sites. This time period has been used to define conditions acceptable for both the Government and the local communities concerned so that work might continue.

The results of geological survey work carried out to date have been included in the "Land-Use Development Plan for the Czech Republic" (approved by Government Decision No. 561 of 17 May 2006) an updated version of which (the "Land-Use Development Plan 2008") should be approved during 2009. The preliminarily selected potential sites should be included in the above Government documentation to ensure that these sites are not threatened by land encroachment.

In 2008, the Ministry of Trade and Industry the Czech Republic by its degree recommended to complete the survey work of the whole territory of the Czech Republic with an assessment of a number of military areas. Five military areas were evaluated from archive data sources in terms of their geological conditions and further criteria of the DGR siting. Consequently, in the middle of the year 2009, two areas were selected as the most favorable location from geological point of view. The results of the geological survey were submitted to the Czech Government for further assessment.

The monitoring objectives in the Czech Republic are given by several points:

- to prove long term safety of the repository – radiation monitoring of the repository vicinity (borehole waters, mine waters, drainage waters),
- to observe the long-term geomechanical behaviour of the rock massive – geotechnical and hydrogeological monitoring for the purpose of long-term safety confirmation,
- to declare safety of the workers – radiation monitoring of the workplace and air, personal monitoring, operational safety,
- to obtain data for safety analyses – hydrogeological monitoring of groundwater movement, geological monitoring of granite rock.
- to identify the opinion of the public in candidate sites – public hearings, public opinion research

The data monitored create the base for safety calculations and preparation of safety reports for the issue of licence applications. Also the method of decommissioning must be included in the documentation applied for the operation licence and licence for management of radioactive waste.

10.1 Societal aspects

The long-term existence of repositories Bratrstvi and Richard (from 60´s and 70´s) is well accepted by local authorities and population. The local authority representatives are members of the RAWRA´s Board, the advisory body of RAWRA. They are regularly informed about the results of radiation monitoring of the repository vicinity and the surrounding environment.

In the case of the deep geological repository, RAWRA has made every effort to keep local communities up to date in both the planning and the results of geological research. There is public opposition in the localities and, hence, as a result of local public pressure work was subsequently suspended. In 2004 the Czech Government effectively suspended the geological survey work in all the candidate sites till 2009.

RAWRA has initiated the setting up of information centres in public libraries of three villages in the regions of the candidate sites. Display posters as well as printed materials and various relevant film clips are available to provide visitors with a wide range of information. A number of computers allow access to information provided on RAWRA´s website and those of other domestic and foreign organisations responsible for radioactive waste management.

Every year, the field trips to an existing URL, repository or DGR site (i.e. Germany, Sweden, Finland etc.) are organised for representatives of local communities from the candidate sites.

10.1.1Expert stakeholders' expectations

All institutions of the state administration, who are involved, i.e., SUJB, Ministry of the Environment, Ministry of Trade and Industry, Ministry of Finance, Czech Mine Office, Czech Geological Survey are expert stakeholders. The expectation of these subjects is to find a status of a nuclear facility fulfilling the legislative requirements during all stages of it´s life. The expert stakeholders use regulatory and control tools in order to achieve that aim.

10.1.2Lay stakeholders' expectations

The community living in the candidate sites wants to be convinced about the safety of such a type of installation. Main scepticism arises from the distrust of the guarantee of the state.
In 2007 RAWRA realized a public opinion research in the candidate sites. The results indicated a number of anxieties, concerning mainly the phase of constructing the repository than in the period of operation. As the following step RAWRA prepares a communication plan aiming at clearing up these anxieties.

The main distresses are as follows:
- negative influence of the DGR construction on local living conditions,
- negative impact on groundwater level,
- fall of real property prices,
- increase of radon level during excavation works
- negative impact of the DGR on the environment at all.

Another important issue resulting from the research of public opinion is the local representatives effort to play more important role in the decision making process. RAWRA strives for the site selection process as transparent as possible and makes efforts to involve local communities in the final decision-making process, for example by participation of the local experts in both the survey process and the subsequent evaluation of the results.
There is no legislative tool for the public to participate in the decision making process other than EIA. Moreover, no compensation or subsidies to local communities in the case of agreement with the geological survey or DGR construction is included in Atomic Act. At present, Decree of the Government 416/2002 assesses the annual subsidy for the community on the cadastre of

which a repository is located. Nevertheless, these subsidiaries are intended only for situation, when repository is already in operation.
RAWRA makes an effort to negotiate the amendment of the Atomic Act through the representatives of Ministry of Trade and Industry and Parliament of the Czech Republic.

10.1.3Legal and regulatory framework

The State Office for Nuclear Safety (SUJB) is the regulatory body responsible for governmental administration and supervision in the fields of uses of nuclear energy and radiation and of radiation protection. The authority and responsibilities of the SUJB includes in particular state supervision of nuclear safety, radiation protection and emergency preparedness, monitoring the status of exposure of the public and personnel handling ionizing radiation sources. The SUJB provides licensing of the activities using ionization radiation from the siting and operation to the decommissioning of nuclear installations.

The basic legislative framework is created by Atomic Act 18/1997 and a number of decrees of the SUJB.

Atomic Act postulates the radioactive waste management fundamentals and principles, and strict requirements on the whole documentation for application approved by SUJB in all stages of repository and other nuclear installation development.

Decree of the SUJB No. 307/2002 on radiation protection sets the main requirements on radiation monitoring of people and repositories in all stages of life:

- the operational exposure is considered according to the dose limits for workers (derived form ICRP standards),
- the monitoring activities are performed according to the monitoring programes approved by SUJB (licence approval).

Act 44/1988 on protection and usage of mineral resources postulates requirements for protection of the territory considered for building of the DGR.

Concerning communication RAWRA has also a statutory obligation to provide information of the public according to the Act 109/1999, on free access to information..

10.2 Physical aspects

The physical aspects of the DGR assumed in the Czech Republic are described in the Reference Project of Surface and Underground Systems of DGR issued in 1999. This project presented next level of studying and development works, helping to technical and economical modelling of DGR and one of its parts has also been a feasibility study of DGR in the Czech Republic. This Reference Project has been few times modified based on new knowledge, last time in 2003 and it is being updated as a Reference Design 2011 project at present.

10.2.1Host rock

Conformable to the Concept and according to the results of DGR development process and also with respect to the geological bedrock of the Czech Republic territory granitic rocks were chosen as a most suitable host rock for DGR construction. As a result of a previous area survey stage, six sites were chosen as suitable to be considered in the next stage of the siting process.
Presently, as a result of Government decision, in the first stage of the evaluation of military areas in terms of their suitability for the siting of a deep geological repository two military areas were

chosen – one as the favoured location and second as a further suitable site. The assessment was based solely on existing geological maps and other available information.

10.2.2 Waste inventory and properties

The prevailing inventory of LILW repositories is composed of ^{137}Cs, ^{63}Ni, ^{14}C, ^{226}Ra, ^{232}Th, ^{90}Sr and ^{238}U.

The spent nuclear fuel from operation of Temelin nuclear power plant (ETE) and Dukovany nuclear power plant (EDU) is stored at the storage in Dukovany power plant. The inventory of waste containing spent nuclear fuel is given by the type of the reactor (VVER-400 for EDU and VVER-1000 for ETE) and burn-up level. New reactor blocks are expected to be built.

Other high-level waste composes of the waste with activity overdrawing the waste acceptance criteria for ILW disposal and spent fuel from research reactors.

The results of a survey of the amount of existing and expected short-lived LILW are given in Table 10-1.

Source	**RW–Operation (m^3)**	**RW Decommissioning (m^3)**	**Average Annual Production (m^3)**
EDU (1985-2025)	10,250	--	256
EDU (2025-2035)	--	3,640	364
EDU (2085-2094)	--	2,385	239
ETE (2000-2042)	12,000	--	285
ETE (2040-2047)	--	620	78
ETE (2090-2095)	--	4,012	669
Total NPP	**32,907**		
Instit. (1958-2000)	2,800		67
Instit. (2000-2095)	5,700		60
Total institutions	**8,500**		

Table 10-1: Survey of the amount of LILW-SL. EDU and ETE – Czech NPPs.

Production of the long lived ILW and spent nuclear fuel is summarized in Table 10-2.

Source	**LILW-LL Operation (m^3)**	**LILW-LL Decommissioning (m^3)**	**SNF (t)**
EDU (1985-2025)	50	--	1,937
EDU (2085-2094)	--	2,000	--
ETE (2000-2042)	50	--	1,787
ETE (2090-2095)	--	624	--
Total NPP	**2,724**		**3,724**
Instit. (1958-2000)	80	5	0.2
Instit. (2000-2050)	150	50	0.3
Total institutions	**285**		**0.5**

Table 10-2: Survey of the Production of LILW-LL (post-processing volume) and Spent Nuclear Fuel. EDU and ETE – Czech NPPs.

10.2.3 Engineered barriers

The basic elements of the Reference Design are similar to Swedish KBS 3V concept of disposal of spent fuel assemblies in granite in boreholes in a vertical position:
Corrosion resistant containers – carbon steel covered by corrosion resistant Ni alloy
layer, with expected minimum lifetime about 1,000 years.
Water impermeable buffer – bentonite Ca-Mg type from deposit Rokle, Czech Republic.

The repository layout, consisting of boreholes with spent fuel waste packages surrounded by bentonite bricks and located in the tunnels 500 m below the surface and a carbon steel canister design for 7 spent fuel assemblies from VVER 440 reactors and 3 spent fuel assemblies from VVER 1000 reactors are presupposed. The basic data are given as follows:

Basic parameters of disposal waste package for VVER440 fuel type:
Amount of SFAs: 7
Fuel type: VVER440
- Fuel state: Whole SFA
- Mechanical stress: External pressure 20 MPa
- Max. surrounding temperature: 110 °C
- Dimensions: Ø 650 Ø 3670 mm
- Weight: 3,500 kg (without fuel)
  5,000 kg (with fuel)
- Material: Carbon steel (2,800 kg)
  Stainless steel (300 kg)
  $AlMgSi_{0,5}$ (400 kg)
  NiCr surface layer

Basic parameters of disposal waste package for VVER1000 fuel type:
Amount of SFAs: 3
- Fuel type: VVER1000
- Fuel state: Whole SFA
- Mechanical stress: External pressure 20 MPa
- Max. surrounding temperature: 110 °C
- Dimensions: Ø 701 Ø 5050 mm
- Weight: 5,430 kg (without fuel)
  7,770 kg (with fuel)
- Material: Carbon steel (4,500 kg)
  Stainless steel (930 kg)
  NiCr surface layer

Distance among boreholes: 5 m – for both fuel types
Distance among galleries: 25 m
Borehole sealing: Bentonite blocks
Disposal waste package temperature: 100 °C

10.2.4 Progressive closure or "one-pass" closure

No final decision about the DGR closure concept has been adopted yet.
The closure concept adopted for LILW repository and monitoring activities expected during decommissioning process could be documented on example of the Richard repository.

In 2006 – 2007 was realized experimental closure of three disposal chambers in Richard repository by technology designed by DBE TECHNOLOGY GmbH. The main feature of this concept is the implementation of “hydraulic cage” around the disposal chambers. This hydraulic cage was realized by backfilling waste drums with special type of concrete and building a high permeable layer (gravel) in gap between the waste/concrete body and wall of the chamber as preferential pathway for groundwater. The principle of the hydraulic cage was adopted as main technology for closure of other chambers. The process of closure of the chambers is continuous: after the space of the chamber is filled up by waste drums, the chamber is backfilled by concrete. At the time the repository is in operation.

Short term geotechnical monitoring was performed in stage of backfilling of the chambers. The purpose of this monitoring was the continuous measurement of the parameters necessary for maintaining the quality of backfill material and for confirming perfect backfill of the all space of the chamber. To achieve and maintain requested quality of the concrete used the hydration heat development was monitored by means of temperature changes measurement. The system of temperature sensors was installed at selected locations at various height levels in the chambers. Visually supervision of the continuous backfilling of the chamber was performed by using a number of simple web cameras installed at suitably chosen positions on the chamber ceiling. The results prove the good quality of the chambers closure.

10.2.5 Disposal concept – architecture

Regardless of an ongoing updating of the original Reference Design 1999 it is still valid in the Czech Republic as follows:

Placement of DGR	
Location:	hypothetic
Dispose spaces depth:	500 m
Surroundings	
Rock massif:	crystalline rock
Middle surface ambient temperature:	10 °C
Pressure on canister:	20 MPa
General design of DGR	
Design of deposition spaces:	– Single-level lay-out
Way of dispose of:	– Vertical into bore-holes
Transport into underground:	– Vertical
Form of deposition SNF:	– Not modified SNF vertically in canisters
Data about deposition fuel:	– Supposed burn-up level: • VVER 440 - 45 000 MWd/tU • VVER 1000 - 48 000 MWd/tU
	– Storage time of fuel elements - 70 years – (time from take-out of the nuclear reactor)
Under-critical stage evaluation :	– Burn up credit coefficient ≤ 0,95

Temperature on canister surface:	– 100°C
Way of sealing for deposition bore-holes with SNF:	– Bentonite (prefab-parts or shot (blown)-bentonite)
Deposition way of other RAW:	– In containers – concrete containers
Modification of RAW at DGR:	– Modification is done only with RAW rising by own activities – at DGR (cementation)

Arrangements of surface area:
- Surface area consists of two basic parts: the active operations and operations servicing the underground repository part

Arrangements of underground area:
- Access by vertical shafts, placement of SNF & HLW at level -500 m, construction of a tech. horizon to provide dewatering at the level of -550 m

Concerning the DGR surface area the object structure was proposed and the philosophy of modules was introduced. Module covers civil objects with the same or similar significance and among which there are technological, material, transport or other relations. This approach allows using solved module(s) for different design options - modular method. In relation to the surface area were created following functional modules:

Module	Name of function module
M1	Mining module
M2	Module of preparation of RAW and SNF for dispose of (active services)
M3	Personnel-managing module
M4	Transport-service module
M5	Bentonite preparation module
M6	Workshops and stores module
M7	Utility services and connections (water supply, sewerage, electricity, compressed air)
M8	Excavated rock handling
M9	Fire protection – module

The major underground parts of the DGR assumed:

- Access tunnel for mining
- Access tunnel for RAW
- Transloading node
- Shaft inset
- RAW shaft or inclined drift
- RAW technical facility
- Repository tunnels
- Personnel and extraction shaft
- Technical and auxiliary facility
- Groundwater treatment
- Repository tunnels in construction
- Ventilation system

Safety principles and safety objectives are given by legislative framework (atomic act, Decree of SUJB No. 307/2002) which is derived from ICRP and IAEA standards and requirements.
According to the legislative the main safety objectives are as follows:
Reasonable assurance must be provided that doses to members of the public will not exceed 1 mSv/yr. To comply with this limit safety calculations consider the dose from waste disposed of in DGR not exceeding more than 0.25 mSv per year and person for normal evolution scenario and for scenarios initiated by an event with low probability the limit is set to 1 mSv/year per person.

The main safety principle adopted by Czech Republic is ALARA principle.

10.2.6Disposal concept – definition of the upstream disposal process management decisions

Not yet defined in disposal process in the Czech Republic. We suppose such a definition as a one of outputs from the Reference Design 2011 in the end of this project in 2011.
In the Czech Republic the system of decision making in case of monitoring is given by legislative. In case of some parameter observed exceeds the limit then certain remedial action is requested.

The system of monitoring of DGR has not been adopted yet. In case of the LILW repository Richard is situation as follows: Monitoring of last stages of the repository operation and following post-closure period is reduced to the control of the conditions of the backfilled chambers. As the closure of the chambers is expected to be gradual, the control will continue during the post-closure period and even during the period of institutional control. The control of the samples of backfilling material kept in similar conditions as these prevailed in the repository will be carry on after the final closure of the repository.

The safety report of the Richard repository premises 300 years of the institutional control after the final closure of the repository. It is predestined after the period of the institutional control all the records about the repository existence are loosed and intrusion of man cannot be excluded. The radiation monitoring during the institutional control will be ensured by the measuring of the bulk activity of selected radionuclides in the borehole and drainage waters and also by the control of samples of filling materials. No other control system is expected.

Good example of decision making for closing of one part of the repository based on monitoring results could be the Richard repository again. Visual observation of waste disposed of in first stages of the repository operation recognized number of non-conditioned waste and waste packages non meeting the waste acceptance criteria. The decision was to remove these waste packages and after conditioning to place them into chambers consequently closed by the system of hydraulic cage.

11. Japanese national context of HLW (RWMC)

11.1 Societal aspects

11.1.1 Expert stakeholders' expectations (AEC, 2009)

With regard to the disposal of high-level radioactive waste, the Nuclear Waste Management Organization (NUMO) is calling open solicitation for volunteer municipalities for preliminary investigation of their area as a site for the repository, but no local government has answered the solicitation. In the Ministry of Economy, Trade and Industry (METI), the Radioactive Waste Subcommittee under the Nuclear Energy Subcommittee of the Advisory Committee for Natural Resources and Energy established measures to strengthen efforts for increasing the possibility to obtain positive answer from municipalities, and, in accordance with these measures, the Agency for Natural Resources and Energy (ANRE) and NUMO are striving for the reinforcement of public relations activities, such as holding many meetings for briefings in various locations of the country. As part of such efforts, the ANRE has been holding 35 such briefings throughout Japan within the framework of "Country-wide Energy-Caravan" from fiscal 2007. The ANRE has also started the events titled as "Radioactive Waste Workshop -- Let's Talk about Waste from the Electricity Generation" in fiscal 2007 in cooperation with civil groups and held it in 15 cities as of fiscal 2008. NUMO has also been developing awareness raising activities by holding workshops, round-table discussions, etc. in various locations in Japan with the theme of Japan's energy situation or geological disposal of radioactive waste (7 workshops and 18 round-table discussions in 2008).

The Advisory Committee on the Evaluation of Framework for Nuclear Energy Policy of the Japan Atomic Energy Commission (AEC) published a report concerning the evaluation of activities related with the promotion of the treatment and disposal of radioactive waste in September 2008. The AEC asked the relevant organizations to strengthen measures to promote the selection of the site for high-level radioactive waste disposal facility, noting that the Committee proposed the Commission to deliberate the need for reconsidering the method of determining the site for disposal facilities if there is no prospect for obtaining expected results despite the continuation of efforts for the coming 2 or 3 years.

11.1.2 Lay stakeholders' expectations,

Under discussion.

11.1.3 Legal and regulatory framework

11.1.3.1 Development of legal systems for the final disposal of HLW (Government of Japan, 2008)

The promotion of nuclear fuel cycle is an important part of Japanese energy policy and nuclear fuel cycle facilities, such as spent fuel reprocessing facility, are going to start full-scale operation in near future. As a step for facilitating nuclear fuel cycle, the government of Japan amended relevant laws in 2007 in order to take necessary measures for steady implementation of the disposal of high level radioactive wastes and long-lived low-heat-generating radioactive wastes (hereinafter it is referred as TRU wastes) generated in the processes of nuclear fuel cycle.

11.1.3.2 Quality improvement of regulatory activities of the NISA (Government of Japan, 2008)

Nuclear and Industrial Safety Agency, METI (NISA) started to develop a management system for the quality improvement of regulatory activities in fiscal 2006 and has been implementing the system since fiscal 2007.

11.1.3.3 Monitoring in regulatory framework (RWMC, 2005)

In 2000, the Nuclear Safety Commission of Japan (NSC) formulated a basic framework for national safety regulations designed to facilitate the formulation of policies that are required to ensure the safety of geological disposal (NSC, 2000). The Commission's report defined the following measures as "safety securing principles": long-term safety securing measures (site selection, engineering measures); and safety assessment measures, which confirm that safety has been ensured. The report also states that safety should be confirmed in each stage of disposal operations, including: site selection (selection of Preliminary Investigation Areas (PIAs), Detailed Investigation Areas (DIAs) and Repository Sites); application for approval to operate; construction; repository operation; and repository closure. It also states that activities including of **monitoring** and inspection may be implemented at each stage, from initial siting to the termination of operations.

11.2 Physical aspects

11.2.1 Host rock (Government of Japan, 2008)

Open solicitation of candidate areas for literature search on possible installation of final disposal facility has been conducted by the NUMO and some local authorities answered it, but site selection has not yet been made.

11.2.2 Waste inventory and properties (NUMO, 2004)

The wastes considered for disposal are vitrified high-level radioactive residues from reprocessing of spent fuel from commercial power reactors. They include wastes returned from reprocessing overseas, by BNFL in the UK and COGEMA in France. In addition, wastes will result from the JNFL reprocessing plant which is planned to begin operations soon at Rokkasho. A summary of the wastes which are expected to arise from reactor operations up to about 2020 is given in Table 11-1 and an indication of the typical waste properties in Figure 11-1. It is clear that the inventory has a model nature and that the characteristics of waste produced over the next couple of decades will reflect variations in reactor operations (e.g. fuel burn-up) and reprocessing / vitrification technology.

Table 11-1: Waste arisings (BNFL, COGEMA, JNFL & JNC reprocessing plants).

	BNFL	COGEMA	JNC	JNFL
Number of HLW canisters already produced and placed in storage (as of Jan. 2003)	616 (at JNFL)		130 (at JNC Tokai)	-
Number of HLW canisters equivalent to the spent fuel presently waiting to be reprocessed	~1,600		~970	~13,300
Additional planned arisings	-		-	~23,400
Totals	~2,200		~1,100	~36,700

N.B.: Based on the current programme, the total amount of vitrified waste is expected to reach ~30,000 canisters around 2013 and ~40,000 canisters around 2020 (MITI, 2000b).

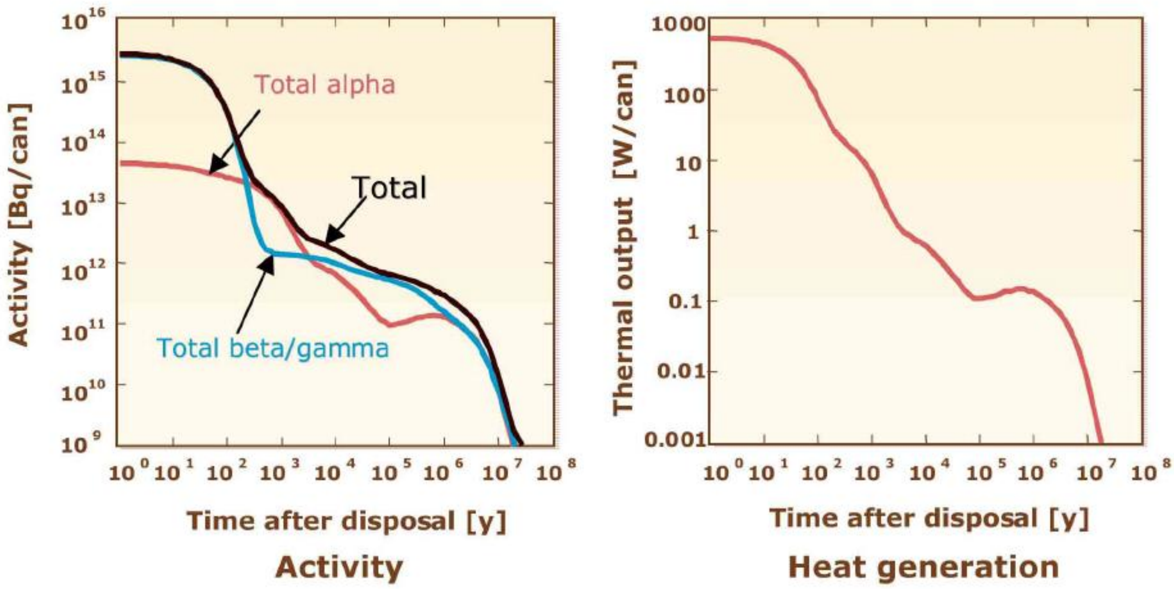


Figure 11-1: HLW properties (type: JNFL; cooling time before disposal: 50 years):
Radioactivity and heat generation per canister of waste as a function of time after disposal.

11.2.3Engineered barriers (NUMO, 2004)

The key components of the H12 EBS developed by Japan Nuclear Cycle Development Institute (JNC, currently reorganized within the Japan Atomic Energy Agency (JAEA)) are a massive steel overpack and a thick buffer of compacted bentonite / sand (JNC, 2000). These barriers were chosen to provide high performance, with a highly conservative design using well-known materials. Figure 11-2 illustrates the main features of this EBS and indicates the multiple processes which work together to provide a robust isolation system.

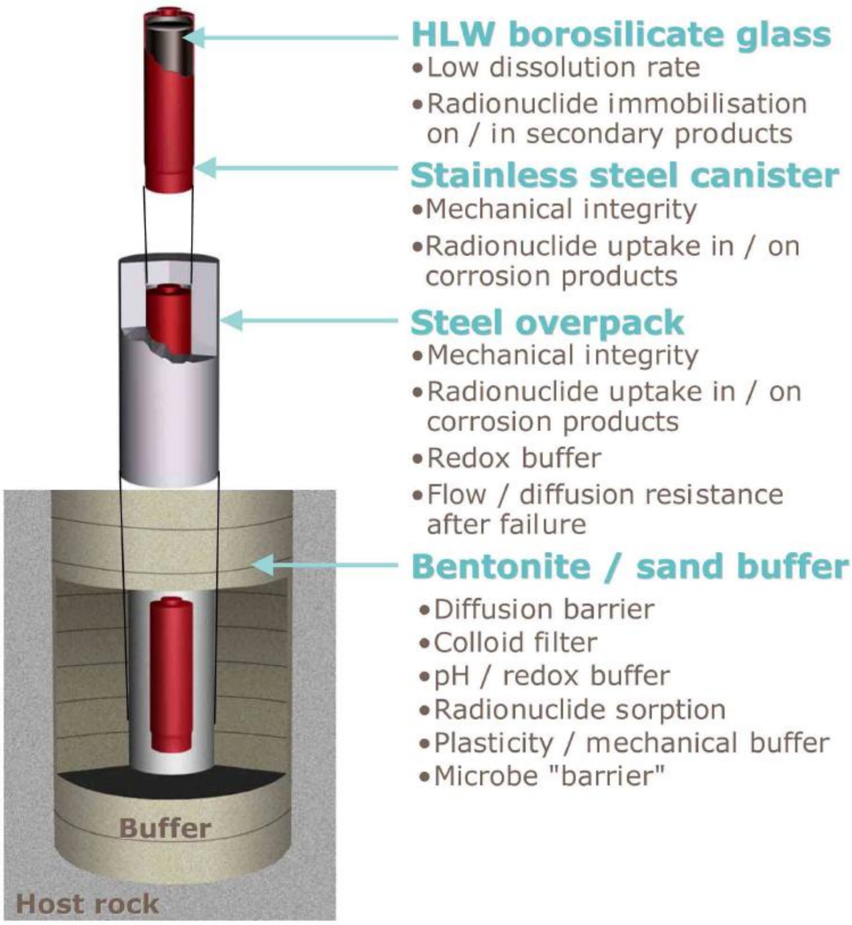
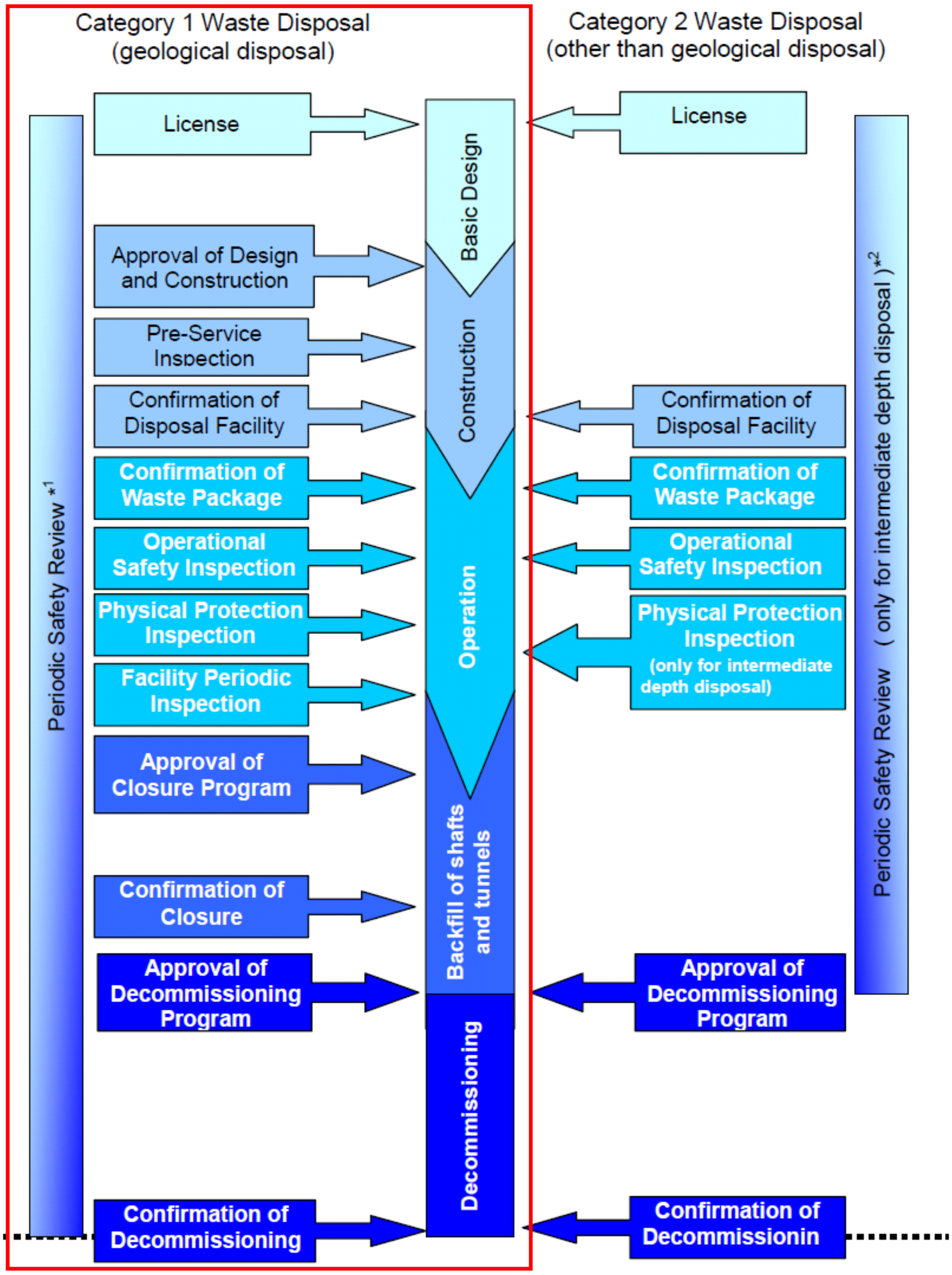


Figure 11-2: H12 engineered barrier system: components and potential roles
(N.B.: not all these barrier roles were analysed in the H12 study).

11.2.4 Progressive closure or "one-pass" closure (Government of Japan, 2008)

Since HLW needs to be isolated from the environment over a long period of time, enhanced regulatory procedures are applied, in addition to the safety regulation for LLW, to ensure reliable closure of an underground facility through approval of a closure program and confirmation that **the steps** have been taken as described in the approved closure program. Figure 11-3 illustrates the safety regulation processes for "Category 1 waste disposal (geological disposal)" and "Category 2 waste disposal (other than geological disposal)".



*1: At an interval not exceeding 20 years after grant of license or when closure program or decommissioning program of auxiliary facility is planned.

*2: At an interval not exceeding 20 years after grant of license or when stage of step-wise control advances.

Figure 11-3: Safety regulation processes for “Category 1 waste disposal” and “Category 2 waste disposal.”

11.2.5 Disposal concept – architecture (NUMO, 2002)

A HLW repository concept includes surface facilities, underground facilities and an engineered barrier system (EBS) laid out in a stable host rock. Surface and underground facilities are designed and constructed taking account of the characteristics of the siting environment. Underground facilities and the engineered barriers are located in a stable host rock more than

300m below ground and have capacity for at least 40,000 canisters of vitrified HLW. In the case of a coastal site, underground facilities can be constructed under the sea-bed. Figure 11-4 illustrates examples of major specifications for inland/crystalline rock repository site and major specifications for coastal / sedimentary rock repository site.

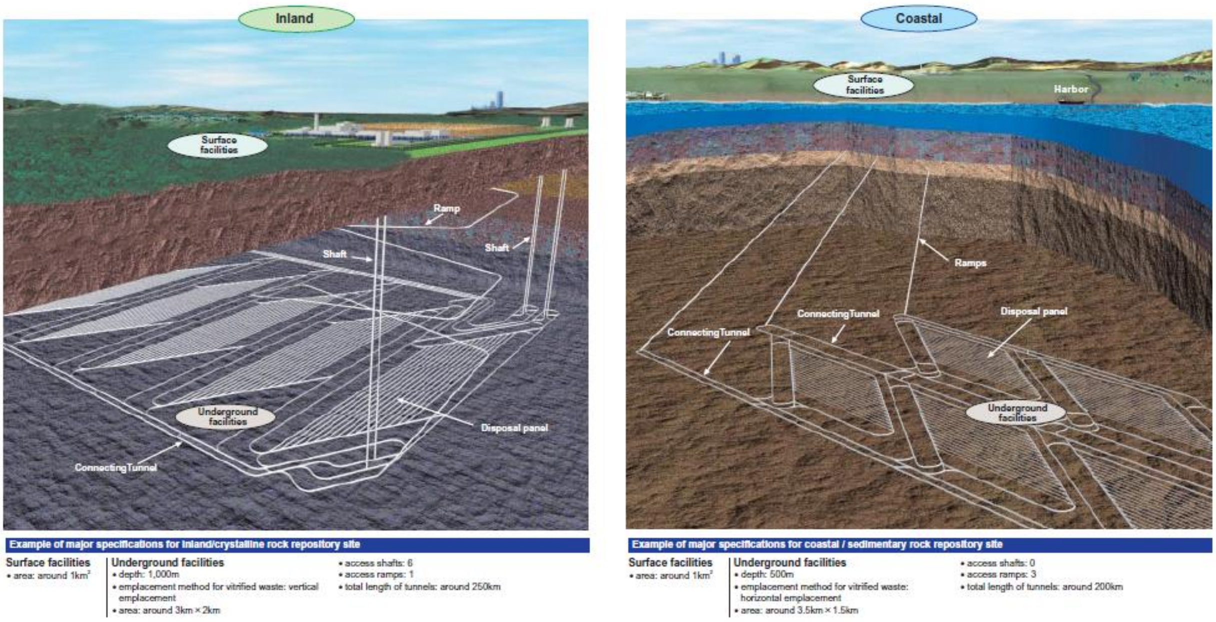


Figure 11-4 illustrates examples of major specifications for inland/crystalline rock repository site and major specifications for coastal / sedimentary rock repository site

11.2.6Disposal concept – definition of upstream disposal process management decisions

Under discussion.

11.2.7Monitoring and Decisional process (RWMC, 2005)

Based on objectives in IAEA Report (IAEA, 2001) and other objectives of monitoring by domestic and overseas authorities and organizations involved in the geological disposal, with considerations of vitrified HLW geological disposal concepts in Japan, objectives of geological disposal monitoring had been broadly classified by RWMC in 2005 as follows:

Objective 1:

Confirming safety performance and the adequacy of the repository's engineered measures,

Objective 2:

Confirming compliance with statutory requirements,

Objective 3:

Providing information for making decisions on policy and operations,

Objective 4:

Understanding the baseline characteristics of the geological environment at Preliminary Investigation Areas, etc. and

Objective 5:

Providing information for public decision-making.

Table 11-2: The objective of monitoring of geological disposal and the description by RWMC

Objective	Description
1. Confirming safety performance and the adequacy of the repository's engineered measures	♦ Confirming whether or not disposal system components function as planned ♦ Confirming design/construction assumptions ♦ Verifying safety assessment models ♦ Judging the need for facility improvements or repairs related to repository operation/construction
2. Confirming compliance with statutory requirements	♦ Confirming compliance with regulations after a closure of repository ♦ Confirming compliance with safety regulations for workers and local residents during construction and operation ♦ Confirming compliance with environmental impact assessment regulations
3. Providing information for making decisions on policy and operations	♦ Providing information for decision-making ♦ Dealing with the retrievability of emplaced waste packages
4. Understanding the baseline characteristics of the geological environment at Preliminary Investigation Areas, etc.	♦ Clarifying the baseline characteristics of the geological environment
5. Providing information for public decision-making	♦ Enhancing the confidence that the public (particularly local residents) have in geological disposal ♦ Compiling databases for future generations

The monitoring is directly connected to all aspects of decision process of the geological disposal mentioned above. Therefore RWMC continues discussing classification of the objective with a technical committee.

11.3 References

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IAEA, Monitoring of Geological Repositories for High Level Radioactive Waste, IAEA-TECDOC-1208, 2001.

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NUMO, Repository Concepts, Relevant information for open solicitation of volunteers for areas to explore the feasibility of constructing a final repository for high-level radioactive waste, 2, 2002.

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NUMO, Development of Repository Concepts for Volunteer Siting Environments, NUMO-TR-04-03, 2004.

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12. US National Context (Sandia)

The National Context for performance confirmation monitoring in the United States of America (USA) encompasses two mature nuclear waste repository programs involving vastly different geology and significantly different missions. However, each program integrates a long-term performance assessment within its safety case and implements a performance confirmation program as part of regulatory commitment. The Waste Isolation Pilot Plant (WIPP) in a salt formation and the Yucca Mountain site in volcanic tuff represent decades of engineering, research and development, and licensing. Additional information can be readily obtained from the respective websites: www.wipp.energy.gov and www.ocrwm.doe.gov.

The National Context for Performance Confirmation is prepared for WP1 of the MoDeRn deliverables and follows a recommended format for order and content. The remainder of this section describes nuclear waste repository monitoring programs in the USA. The experience, rationale, decisions, regulations, and strategy for testing and monitoring programs as implemented in two repository programs provide the national context. The material that follows is arranged to be responsive to the goals of the MoDeRn project. These goals include establishing societal bases for performance confirmation as well as the more tangible regulatory bases. The context includes physical characteristics of the disposal concept and brief acknowledgement of the step-wise licensing process.

12.1 Societal aspects

12.1.1 Expert stakeholders' expectations

The regulatory authority can be viewed as the primary stakeholder on behalf of the citizens of the USA. The jurisdiction and responsibility of the regulators are promulgated within federal documents. The two repository programs in the USA have employed expert oversight as established within the regulatory framework as well as independent expert oversight by the national academies, state governments and other groups.

12.1.2 Lay stakeholders' expectations

Lay stakeholder expectations may be evaluated in the context of the organizations that represent their interests. These stakeholders may be indentified in the regulations, such as affected State or affected Indian Tribes, and subsidized by conditions of the regulatory Act. Other lay stakeholders can comprise volunteer independent oversight groups, which can have favorable or unfavorable disposition toward the repository project.
The licensing experience for WIPP, as an example of formal societal stakeholder involvement, has included several independent oversight groups:

- National Research Council since the 1950s.
- New Mexico Governor's Advisory Committee established in 1975.
- Environmental Evaluation Group established in 1979.
- Department of Energy Oversight Bureau began in 1999.
- Peer reviews throughout the project history.
- Citizens Advisory Groups/Boards throughout the project history.
- PECOS Management since 2005.

In addition, several informal groups largely against the WIPP project were engaged through open meetings, the review process, and systematically as part of the transparent licensing process.

12.1.3 Legal and regulatory framework

The nuclear waste repository programs in the United States involve waste inventories and geologic settings that are very different; however, both programs are governed by the Code of Federal Regulations (CFR). The most important regulations are:

- 10 CFR 60 Disposal of High-Level Radioactive Wastes in Geologic Repositories
- 10 CFR 61 Licensing requirements for Land Disposal of Radioactive Waste
- 10 CFR 63 Disposal of High-Level Radioactive Waste in a Geologic Repository at Yucca Mountain, Nevada
- 40 CFR 191 Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Wastes
- 40 CFR 194 Criteria for the Certification and Re-Certification of the Waste Isolation Pilot Plant's Compliance With the 40 CFR Part 191 Disposal Regulations
- 40 CFR 197 Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada.

The 10 CFR series of regulations is authored by the Nuclear Regulatory Commission (NRC). In general, these monitoring requirements focus on the operational period. They require a confirmatory monitoring program to be initiated prior to operations and continuing until site closure. Confirmatory monitoring includes tests, experiments, and analyses that are conducted to evaluate the adequacy of the information used to demonstrate compliance with the site specific pre-closure and post-closure performance objectives. Performance assessment is an important instrument for compliance certification. A risked-informed and performance-based evaluation of the performance assessment helps quantify monitored parameters in the confirmation program.

The 40 CFR series of regulations is authored by the Environmental Protection Agency (EPA). While the NRC regulates commercial nuclear power activities, the EPA has historically regulated or authored the requirements for disposal of waste generated or owned by the U.S. government. In general, these regulations require operational and post-closure monitoring of the disposal system. Operational monitoring ensures that dose limits to the public and the environment are not exceeded. These regulations also impose confirmatory monitoring requirements to identify parameters important to performance assessment that can be monitored during the operational and post-closure periods.

12.2 Physical aspects

Yucca Mountain is the site of America's first planned repository for spent nuclear fuel rods and solidified high-level radioactive waste. The nuclear material would be stored in tunnels excavated in volcanic terrain deep underground, yet hundreds of meters above the water table. The disposal concept and natural and engineered barriers are illustrated in Figure 12-1 below. The engineered barriers envisioned for Yucca Mountain include the waste package, the waste form, drip shields and other components within the emplacement drift.

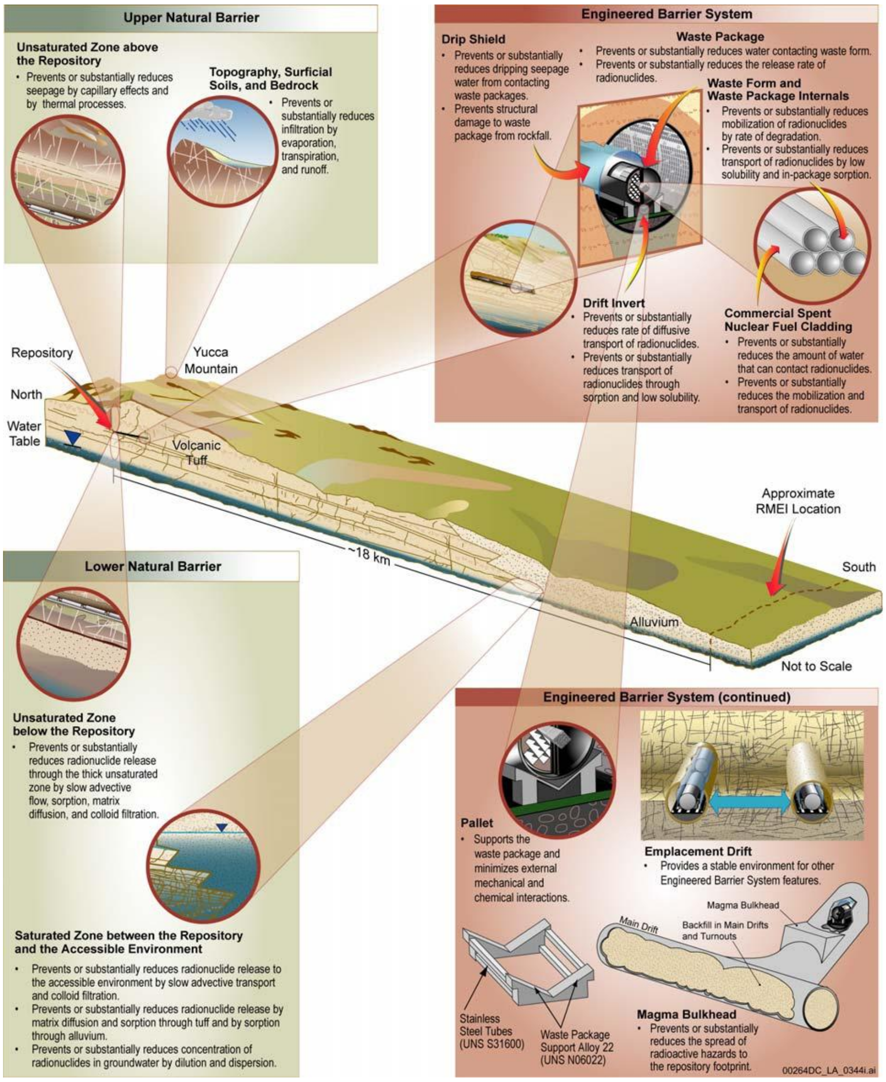


Figure 12-1. Schematic of engineered and natural barriers at Yucca Mountain.

The Waste Isolation Pilot Plant, or WIPP, safely disposes of the nation's defense-related transuranic radioactive waste. The inventory includes contact handled waste, which is stacked vertically in the disposal rooms, and remote handled waste, which is inserted into horizontal holes drilled into the pillars adjacent to the disposal rooms. The repository layout is illustrated in Figure 12-2. Located in the Chihuahuan Desert, outside Carlsbad, New Mexico USA, WIPP began disposal operations in March 1999.

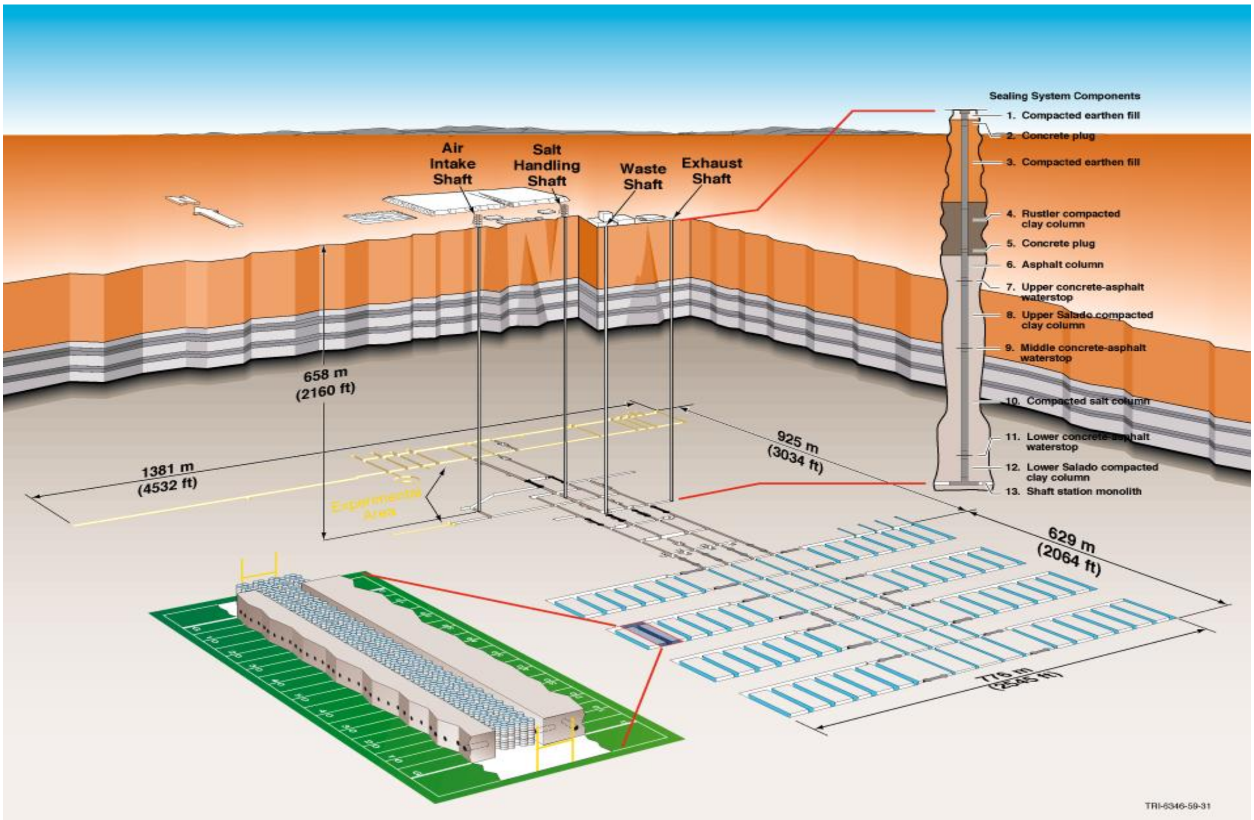


Figure 12-2. Schematic of the WIPP facility.

WIPP barriers take advantage of positive isolation characteristics of the salt formation. For purposes of this national context, barriers are defined as any material or structure that prevents or substantially delays movement of water or radionuclides toward the accessible environment, which includes the shaft sealing system, the panel closure system and a chemical buffer of magnesium oxide.

WIPP and Yucca Mountain represent two very different repository concepts; however, each has clear requirements for performance confirmation monitoring. WIPP has been in operation for more than ten years, and has met regulatory requirements for recertification every five years. Yucca Mountain has followed a well defined, staged decision process for site recommendation, licensing, construction, and possible future milestones as illustrated in Figure 12-3.

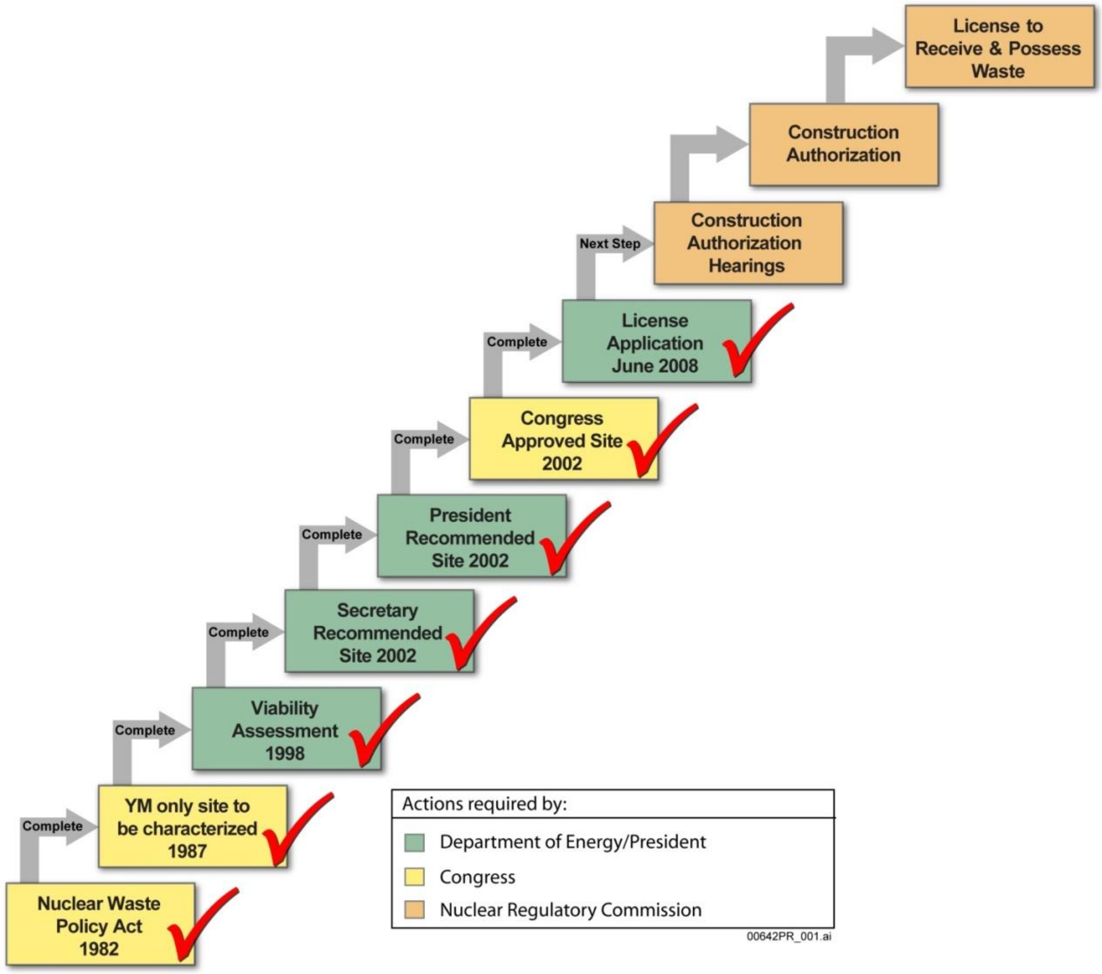


Figure 12-3. Step-wise decision process for Yucca Mountain.

Systematic decisions are consistent with a well defined licensing and review process for each repository program. Both WIPP and Yucca Mountain programs have ongoing monitoring programs. Each program has made allowances for retrieval. For example, Yucca Mountain operations include the possibility of retrieval by essentially reversing the placement process using a transportation and emplacement vehicle. Because room closure is relatively rapid at WIPP, retrieval as a reverse process of placement is only possible for several years, after which waste could be recovered with increased effort.

Waste Isolation Pilot Plant Monitoring

A monitoring program is based on assumptions and regulations for the disposal concepts and waste types. Monitoring requirements logically derive from the functional, operational, and post-closure goals. Monitoring a radioactive waste disposal facility ensures protection of the public and environment from current and potential future hazards. This is accomplished by undertaking activities that confirm compliance with applicable protective regulations and through activities that confirm critical aspects of the expected performance of the repository.

Because monitoring is a confirmatory activity, information gathering occurs before and during operations, as well as after the facility is closed. Monitoring includes gathering data prior to the start of operations such that operational monitoring includes a pre-operational element. The

WIPP context includes specific categories of monitoring that apply to a disposal system, which are termed environmental monitoring, compliance monitoring, and performance confirmation: Environmental monitoring includes sampling and evaluation of air, surface water, groundwater, sediments, soils, and biota for radioactive contaminants. This type of monitoring determines public and environmental impact of the site. Comparisons are then possible between baseline data gathered before site operations and data generated during disposal operations.

Compliance monitoring is defined here as monitoring activities used to comply with regulatory requirements for general siting, facility operations, and decommissioning. These requirements are identified in existing regulations, state agreements or organizational agreements.

Performance Confirmation constitutes a program of tests, experiments, and analyses that is conducted to evaluate the adequacy of the information used to demonstrate compliance with the site specific pre-closure and post-closure performance objectives. Performance confirmation monitoring starts with initial site characterization and is completed at some point after site closure.

Periodic review of these monitoring parameters is necessary to meet the intent of assurance requirements:

> *Disposal systems shall be monitored after disposal to detect substantial and detrimental deviations from expected performance. This monitoring shall be done with techniques that do not jeopardize the isolation of the wastes and shall be conducted until there are no significant concerns to be addressed by further monitoring.*

The U.S. Department of Energy oversees and directs the monitoring program to ensure compliance with the EPA monitoring and reporting requirements. Observations beyond the acceptable range of trigger values represent a condition that requires further evaluation. This approach assures that conditions that challenge expected repository performance are recognized as early as possible. These conditions may include data inconsistent with the conceptual models implemented in performance assessment or invalidation of assumptions and arguments used in screening features, events and processes.

Decisions for selection of parameters to be monitored and analyzed should be made accounting for regulatory requirements, modeling assumptions, features, events, and risk information derived from performance assessment results. Uncertainty and sensitivity analyses should quantify the importance of the parameters that are candidates for monitoring in the performance confirmation plan. Uncertainty and sensitivity analyses should include a sufficient set of diagnostics to provide justification for the parameters selected as well as the parameters not selected for performance confirmation monitoring.

Yucca Mountain Monitoring

The purpose and objectives of the performance confirmation testing and monitoring program, as stated in the regulations are to conduct a program to:

> *. . . evaluate the adequacy of assumptions, data, and analyses that led to the findings that permitted construction of the repository and subsequent emplacement of the wastes. Key geotechnical and design parameters, including any interactions between natural and engineered systems and components, will be monitored throughout site characterization, construction, emplacement, and operation to identify any significant changes in the*

conditions assumed in the License Application that may affect compliance with the performance objectives…

Confirmation monitoring and testing is concerned mostly with post-closure performance of the repository; however, activities also address waste retrieval and testing directed by regulation (such as seal testing). The performance confirmation program must:

- Evaluate the effectiveness of design features intended to perform a post-closure function during repository operation and development
- Evaluate information used to assess whether natural and engineered barriers function as intended
- Confirm that subsurface conditions and geotechnical/design parameters are as anticipated and that changes to these conditions and parameters are within limits assumed in the license application
- Confirm that the waste retrieval option is preserved
- Monitor waste package conditions.

The regulatory requirements from 10 CFR Part 63 (promulgated specifically for Yucca Mountain) were used to guide development of the governing document for performance confirmation. The performance confirmation plan describes twenty activities designed to capture a satisfactory range of confirmatory monitoring and testing to meet the regulatory requirements. Implementation of the performance confirmation activities requires the opportunity exist to execute the monitoring program. For example, access to wells and associated state permits must be available before certain saturated zone testing can be conducted; likewise, new underground excavation would be necessary before detailed mapping of the opening is possible. The activity itself needs to be planned, prioritized, and budgeted in a consistent manner to allow its successful implementation.

The performance confirmation program for Yucca Mountain is responsive to regulatory requirements and acceptance criteria. It is designed to test the adequacy of assumptions, data, and analyses that are used in the evaluation to permit construction of the repository and direct subsequent waste emplacement operations. The performance confirmation program provides information, where practicable, to evaluate those subsurface conditions encountered and changes in those conditions during construction and waste emplacement operations are within assumed limits. This includes monitoring subsurface conditions and performing tests to confirm geotechnical and design assumptions that are the basis for compliance with the preclosure performance objective for retrievability. The program provides information to evaluate if the natural and engineered systems and components that were designed or assumed to operate as barriers after permanent closure are functioning as intended.

A risk-informed approach is applied to the performance confirmation program. A decision analysis process was used, which focused the confirmation program on the perceived risk areas. Activity evaluation included an assessment of the parameter sensitivity, confidence, and accuracy. The risk-based aspect of the confirmation activity relied upon correlation to performance assessment calculations. Testing and monitoring considered performance of the individual barriers and the total system. Program development, activity selection, and refinement included consideration of factors such as synergy among activities, feasibility, operability, and cost.

The confirmation plan that supports the construction license application provides a clear cross-walk between the requirements and implementation. Specific confirmation activities will have stand-alone test plans, which will define parameter ranges, condition limits, and notification criteria. Despite the rigor of the specific performance confirmation test plans, the long-term testing and monitoring program for Yucca Mountain includes flexibility for changes. In fact, regulations require updates and amendments as the program progresses. For example, regulations state that an application to amend the license to permit permanent closure must include an update of the assessment of the performance of the geologic repository for the period after permanent closure. The updated assessment must include any performance confirmation data collected under the program pertinent to compliance.

The Yucca Mountain performance confirmation program is undertaken to meet regulatory requirements, which include a schedule for planned activities and an assessment as to whether that schedule is sufficient to meet the general provisions. Figure 12-4 presents the schedule for testing and monitoring activities defined for performance confirmation purposes at Yucca Mountain. Eleven activities undertaken for site characterization will be continued as part of the performance confirmation program; these are listed in the first column of the schedule. The three performance confirmation test plans that are currently being implemented are shown in the second column in Figure 12-4, Baseline Phase, and are labeled Active PC. These are followed by four ongoing science activities (corrosion testing, waste form testing, saturated zone monitoring, and saturated zone alluvium testing) that have some level of testing and monitoring leading to the license application. Figure 12-4 further illustrates the opportunistic nature of performance confirmation monitoring.

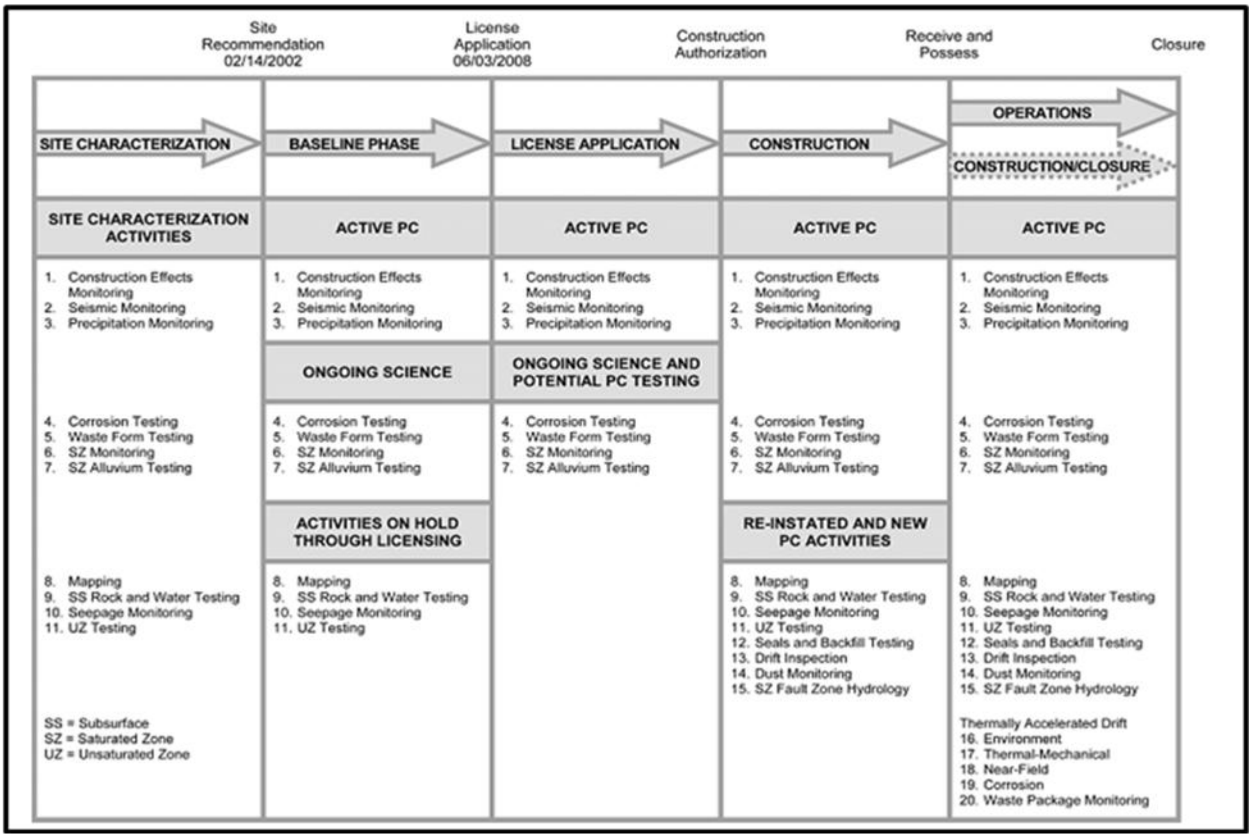


Figure 12-4. Performance confirmation schedule for Yucca Mountain.

Performance confirmation adds to public confidence because it is intended to demonstrate that the repository is responding as expected and as represented in the licensing basis. Elements of the confirmation program started during site characterization and are expected to be continued over the life of the project. The regulatory nature of performance confirmation test plans necessitates care be exercised in their definition, particularly with regard to selected parameters, ranges, and reportable conditions. Elective testing undertaken in baseline science programs will be instrumental in quantifying the appropriate parameters for some confirmation activities. A successful science program includes transparent public outreach that includes a process to reevaluate, reexamine, and modify activities as the state of understanding changes.

13.Swedish National Context (SKB)

13.1 General

Swedish Nuclear Fuel and Waste Management Co, SKB, was formed in the 1970´s and is owned by the companies that own the Swedish nuclear power plants. SKB's assignment is to manage and dispose of radioactive waste from Swedish nuclear power plants in order to ensure safety for human beings and the environment over very long times. More than 30 years of research and development has led SKB to put forward the KBS-3 method for final disposal of spent nuclear fuel. This method is based on three protective barriers. The spent nuclear fuel is first encapsulated in copper canisters with cast iron inserts containing the spent nuclear fuel. Embedded in a bentonite clay buffer, the canisters are subsequently placed in deposition holes in crystalline bedrock at a depth of about 500 metres, see Figure 13-1. The deposition tunnels are backfilled with bentonite and sealed with a concrete plug. Rock caverns, transport and main tunnels are backfilled and top sealing is placed after completion of the disposal.

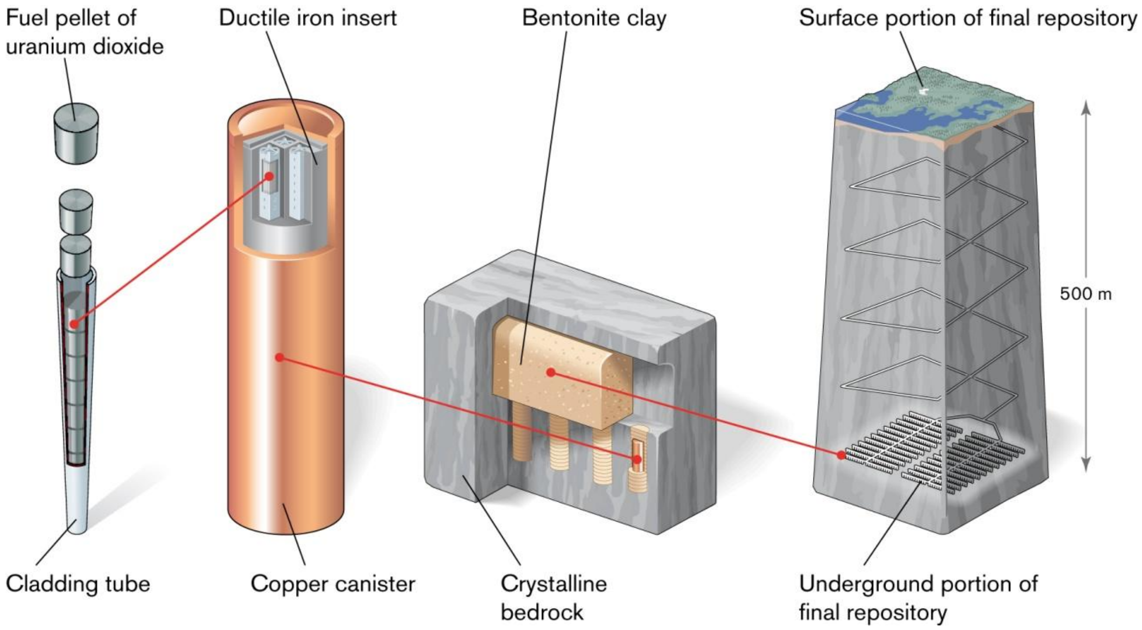


Figure 13-1. The KBS-3 concept for disposal of spent nuclear fuel.

SKB is responsible for the system of facilities used to handle all nuclear waste from the Swedish nuclear power plants. These facilities include the central interim storage for spent nuclear fuel (Clab) near Oskarshamn, and the final repository for short- and medium-lived radioactive waste (SFR) in Forsmark, see Figure 13-2. Transport is by sea using the customised vessel (M/S Sigyn).

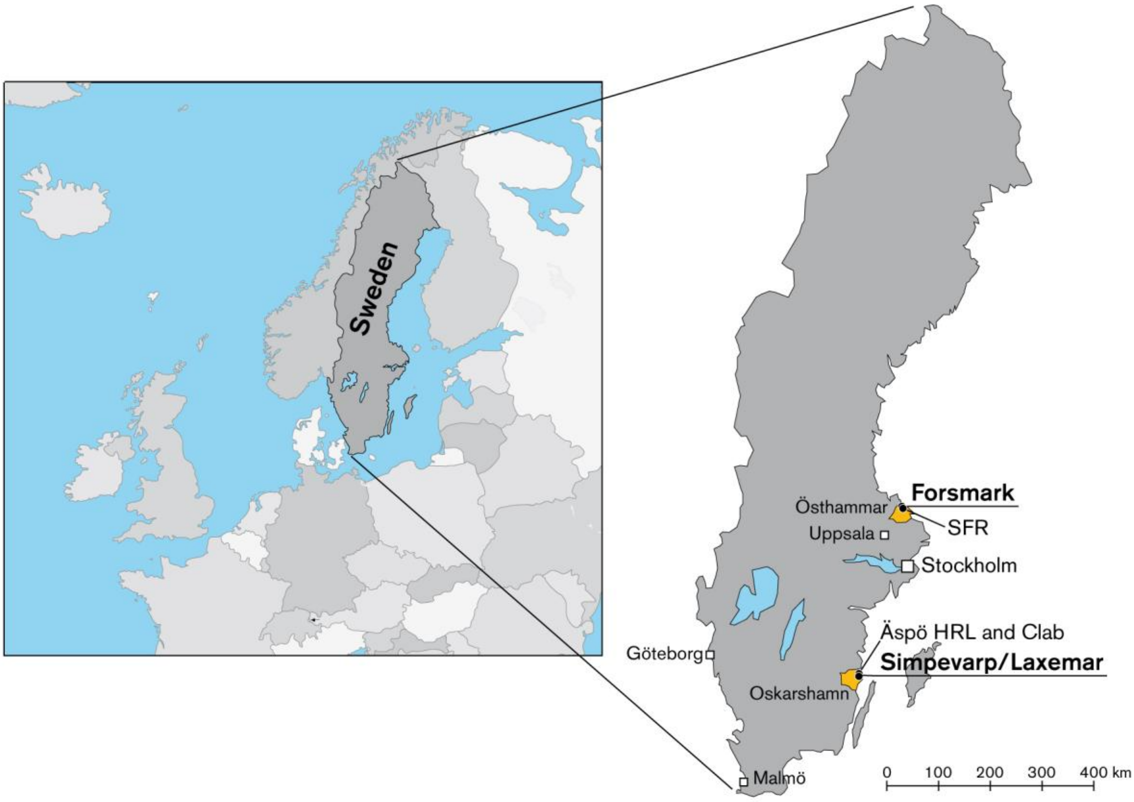


Figure 13-2. The locations of the central interim storage for spent nuclear fuel (Clab) and Äspö HRL near Oskarshamn, and the final repository for short-lived radioactive waste (SFR) in Forsmark.

13.2 Research

SKB has been conducting advanced research for more than thirty years with a special focus on the final disposal of spent nuclear fuel in a geological repository. During the 70´s and 80´s the geoscientific research was focussed on national studies concerning site investigations and international projects such as the Stripa project in south-central Sweden, and the construction of the Äspö Hard Rock Laboratory (Äspö HRL) situated north of Oskarshamn (Figure 13-2). Major aims of the pre-investigation and construction phases of the Äspö HRL were to verify pre-investigation methodology and to finalise methodology for detailed characterisation of rock mass. The facility is now used to demonstrate repository technology and the functionality of important parts of the repository system (KBS-3). The Äspö HRL provides authentic environment where various technical solutions are subjected to full scale testing over different time scales. Experiments are carried out at a depth of approximately 500 metres, involving both Swedish and international experts. In the *Bentonite Laboratory*, which is part of the Äspö HRL, complementary testing is done to determine how the bentonite clay for production of the buffer and the backfill behaves at various conditions, thereby complementing underground activities. The *Canister Laboratory* located in Oskarshamn is where the technology for the encapsulation of spent nuclear fuel in the copper/cast iron canisters is being developed and tested.

13.3 Repository siting and site investigations

A siting process was initiated some 20 years ago, involving regional studies and pre-studies in selected municipalities, in order to locate candidates for a repository for the final disposal of spent nuclear fuel /Johansson 2006/. Subsequent analyses and site investigations at two localities resulted in the selection in June 2009 of Forsmark in the municipality of Östhammar as the site for the final repository. In 2011 SKB will submit applications to the Swedish Radiation Safety Authority (SSM) and to the Environmental Court to construct the final repository for spent nuclear fuel in Forsmark.

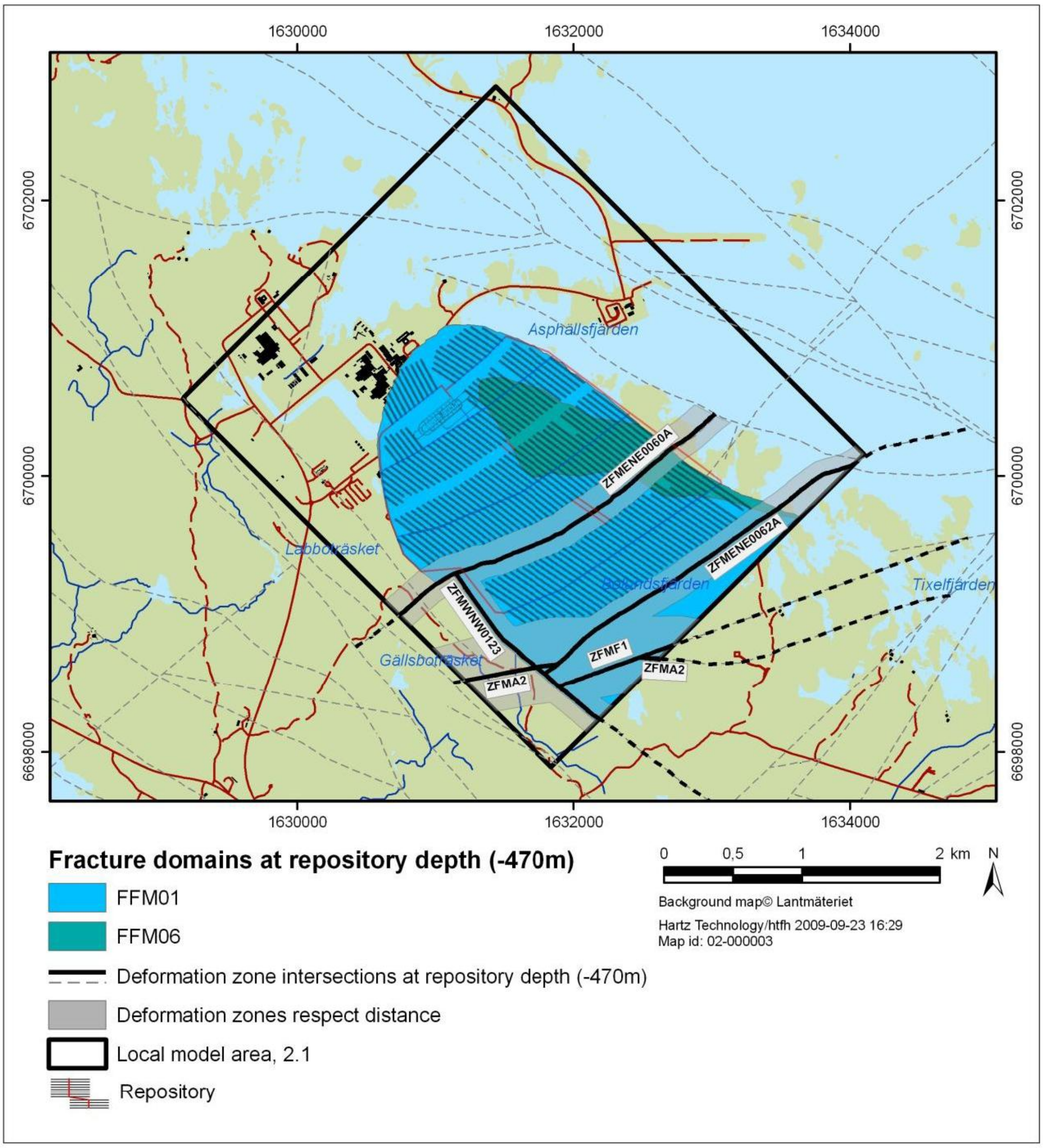


Figure 13-3. Reference layout for the repository at Forsmark, also showing respect distances and the deformation zones requiring the respect distances.

The site investigations have included surface and airborne surveys as well as drilling of a large number of cored and percussion-drilled boreholes in which various types of investigations were made. The site investigations were performed in a staged manner where site investigation data at a particular time (data freeze) have been used to develop models and integrated descriptions of the site /SKB 2008/. The disciplines forming the base for the site-descriptive models (SDM) include geology, thermal properties, rock mechanics, hydro-geology, hydro-geochemistry, transport properties and surface ecology. The Forsmark site features a relatively homogeneous and structurally controlled lithology and is characterised by a low frequency of conductive fractures at repository depth, and hence low groundwater flow /SKB 2008/. The SDM was used to select a suitable repository depth and for devising a layout of the repository /SKB 2009/, including necessary adaptation of the design within the two fracture domains FFM01 and FFM06 and to existing geological entities, including deformation zones, see Figure 13-3. The SDM together with the repository layout formed the base for the safety analysis SR-Site /SKB 2011/.

13.4 Types of waste and disposal concept

The Swedish program involves three types of nuclear waste: operational waste, decommissioning waste and spent nuclear fuel. Operational waste constitutes 85 per cent of all nuclear waste, mostly low- and intermediate-level, although some long living nuclides are present in these wastes. Decommissioning waste, involving large quantities of scrap metal and concrete, is generated when nuclear power plants are dismantled. Like operational waste, most of this waste is low and intermediate-level. Spent nuclear fuel, constitutes the smallest but most hazardous part of the total quantity of waste. Around 12,000 tonnes of spent nuclear fuel is forecasted to arise from the currently approved Swedish nuclear power programme (where the last of the 10 operating reactors is planned to end its operation in 2045), corresponding to roughly 6,000 canisters in the repository.

The major part of the nuclear fuel to be deposited consists of spent fuel from the operation of the twelve Swedish nuclear power plants (two reactors already decommissioned), which are either of boiling water reactor (BWR) type or pressure water reactor (PWR) type. The majority of the fuel used in the reactors consists of uranium oxide fuel (UOX), with minor amounts of mixed oxide fuel (MOX) emplaced in different canister inserts, see Figure 13-4.

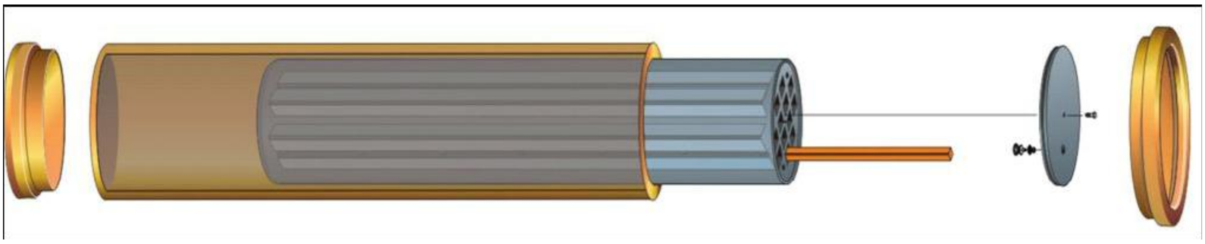


Figure 13-4. Exploded generic view of the canister components (from copper tube, cast iron insert, steel lid for insert and copper lid).

The reference buffer material, which surrounds the canister, is bentonite clay with high montmorillonite content. The role of the buffer is to establish and maintain a high swelling pressure to keep the canister centred in the hole, a low hydraulic conductivity to prevent groundwater flow and with an allowed stiffness and shear strength to protect the canister from damage due to minor rock movements.

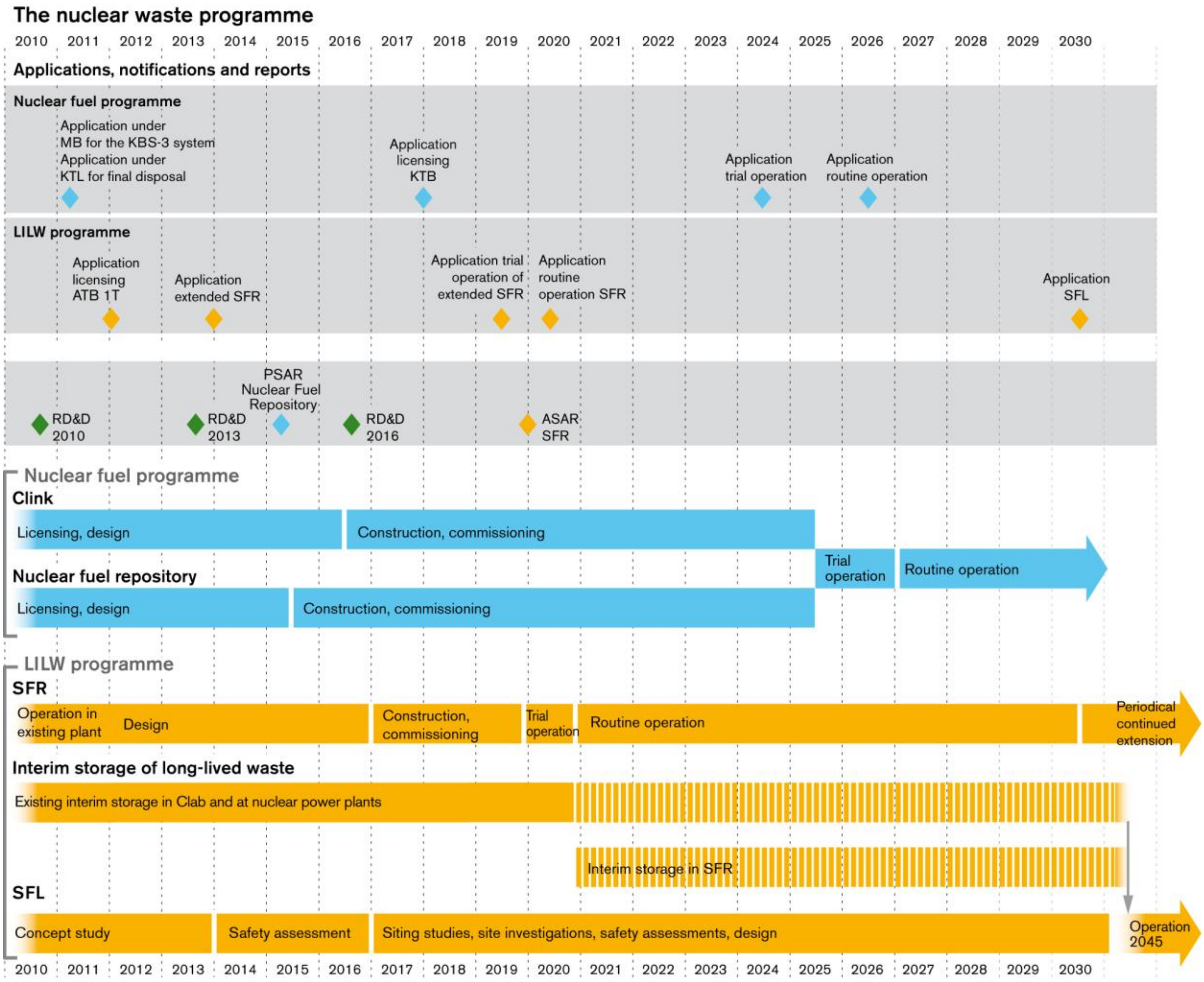
13.5 Legal and regulatory framework

Nuclear operations, including long-term safety of nuclear waste repositories, require permits in accordance with the Swedish Environmental Code and Nuclear Activities Act. The Nuclear Activities Act states that a license application must address radiation protection and short and long-term nuclear safety. The Environmental Code specifically requires a description of the potential impact of the planned operations on human beings and the environment.

The Environmental Impact Assessment (EIA) is prepared by the operator in consultation with authorities, municipalities, organisations, the general public and individuals who are likely to be affected. Consultations regarding the final repository and the encapsulation facility for the spent nuclear fuel were initiated in 2002 and will continue until all the license applications have been submitted. In late 2006 SKB submitted an application for a permit in accordance with the Nuclear Activities Act for the encapsulation facility and for the Central Interim Storage Facility for Spent Nuclear Fuel (Clab). SKB is planning to submit the equivalent application for the final repository for spent nuclear fuel during the first half of 2011. SKB will at the same time apply for a permit in accordance with the Environmental Code for the final disposal system, including the Clab, the encapsulation facility (Clink) and the final repository.

13.6 Outlook on future work

SKB’s future work on nuclear waste is organised in two main programmes; the Nuclear fuel programme and the Loma programme (including enlargement of the SFR facility and work on the *repository for other types of long-lived waste (SFL)*. These programmes manage handling of permits, design, construction and operation of the encapsulation facility at Oskarshamn and the final repository at Forsmark, respectively. The current time schedule for future work is outlined in Figure 13-5. Work within the nuclear fuel programme includes development of a programme for detailed characterisation during the underground development of the final repository and further technical development of the engineered barriers. The former also includes plans for monitoring during the construction and operation phases of the repository.



ATB 1T	Transport cask for long-lived waste	MB	Environmental Code
Clink	Facility for central interim storage and encapsulation of spent nuclear fuel	PSAR	Preliminary Safety Analysis Report
RD&D	Programme for research, development and demonstration	ASAR	As-operated Safety Analysis Report
KTB	Transport cask for canisters with spent nuclear fuel	SFL	Final repository for long-lived waste
KTL	Nuclear Activities Act	SFR	Final repository for short-lived radioactive waste

Figure 13-5. SKB's main time schedule for carrying out the Loma and Nuclear Fuel programmes.

13.7 References

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