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- P R I S M -

The International Project on

PRACTICAL ILLUSTRATION AND USE OF THE SAFETY CASE CONCEPT IN THE MANAGEMENT OF NEAR-SURFACE DISPOSAL

Disposal Facility Design Task

7 December 2012

Version 1.0 Final Draft, 7 December 2012

REF. PRISM/Disposal Facility Design WG

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1 INTRODUCTION

The International Atomic Energy Agency (IAEA) has been sponsoring a major international project on the safety of near-surface radioactive waste disposal. The project, called PRISM, is examining the PRactical Illustration and use of the Safety Case in the Management of near-surface radioactive waste disposal. The project has been conducted within the context provided by the IAEA Safety Requirements and Safety Guides for near-surface radioactive waste disposal.

It is widely recognised that the results of safety assessment calculations provide an important contribution to the safety arguments for a disposal facility, but that safety assessment calculations alone cannot adequately provide confidence in the safety of the disposal system. Safety assessment needs to be considered with a broader range of arguments that justify radioactive waste disposal; that is in a 'safety case'. In this document, the term safety case is used to refer to this broad range of arguments and activities. However, it is recognised that, in some programmes, this broad range of arguments and activities has been addressed without using the term safety case.

The PRISM project has been concerned with the nature and use of the safety case over the lifecycle of a near-surface disposal facility. The PRISM project was a successor to earlier IAEA projects including the NSARS, ISAM and ASAM projects (IAEA 2001a, b; 2004; 2006), which focused on near-surface disposal and particularly on safety assessment methodologies and their application. The PRISM project has drawn on the findings of these previous projects, but provides a distinct focus on practical issues related to implementation of disposal that should be of interest to safety assessors and safety case developers, regulators, and disposal facility managers and/or operators. Compared to the earlier projects, the emphasis has shifted from the details of safety assessment and calculations, to questions of practical implementation (i.e. how near-surface radioactive waste disposal can be managed using the safety case).

2 THE PRISM PROJECT

2.1 OBJECTIVES

The high-level objective of the PRISM project was to share experience and communicate good practice concerning:

- The components and expectations of the safety case and their evolution over the lifecycle of a near-surface radioactive waste disposal facility.
- Decision making at different stages in the facility lifecycle, using the safety case.

2.2 SCOPE

PRISM started in March 2009 and was scheduled for completion at the end of 2012. The project focussed on exchanging experience and communicating good practice. Participants described and discussed experience of implementing and operating disposal facilities with a wide range of designs, waste characteristics and regulatory frameworks at different stages of development. The project considered the applicability of different approaches in these different circumstances.

PRISM looked at the content and structure of a safety case and considered how a safety case can be used in the management of a near-surface disposal facility. A key issue is the changing nature of the safety case over the lifetime of a disposal facility.

The project considered all types of near-surface radioactive waste disposal facilities, including Very Low-level Waste (VLLW) facilities, Low-level Waste (LLW) facilities, Intermediate-level Waste (ILW) facilities, boreholes, silos, shallow caverns and facilities used for the management of mining and mineral processing waste. The scope of the project includes both new and existing disposal facilities.

2.3 ORGANISATION

Four Working Groups were established to address specific issues (Figure 2.1):

- Working Group 1 - Understanding the safety case.
- Working Group 2 - Disposal facility design.
- Working Group 3 - Managing waste acceptance.
- Working Group 4 - Managing uncertainty.

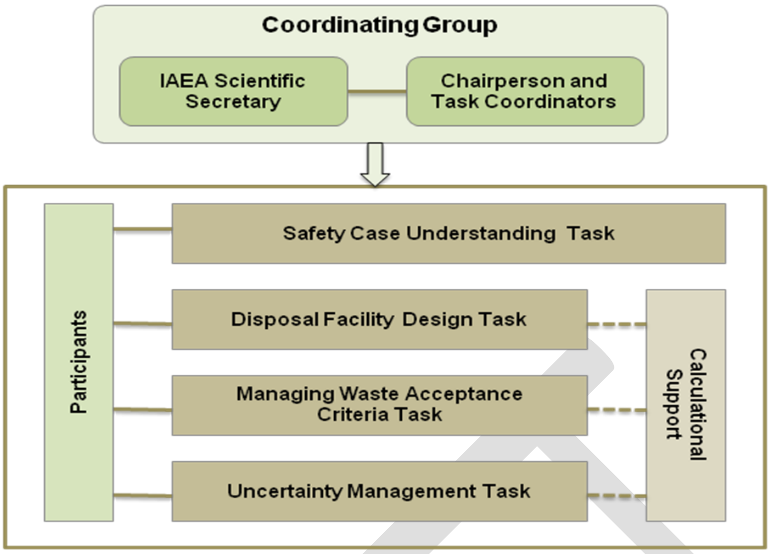

Figure 2.1 PRISM working groups and project structure.

This report addresses the topic of disposal facility design.

3 PRISM WORKING GROUP ON DISPOSAL FACILITY DESIGN

The safety case is an important management tool for guiding and justifying decisions on disposal facility design, development and operation. The Disposal Facility Design Working Group has been identifying the various factors that may influence disposal facility design, and exploring approaches that can be used for developing and justifying the design, operation and eventual closure of near-surface disposal facilities. The working group has sought to compile information at a level that will be of use to disposal facility managers and staff working on the safety case for a disposal facility.

3.1 OBJECTIVES

The specific objectives of the Disposal Facility Design Working Group were to share and exchange information, and communicate good practice on:

- How the safety case can be developed and used on an ongoing basis to support management decisions on facility design and modification.
- How decisions on the design, extension and improvement of near-surface disposal facilities can be informed by, and justified using the safety case.

The Disposal Facility Design Task complements the work on Understanding the safety case undertaken within PRISM Task 1 by providing a more detailed examination of how the safety case can be used to assist specifically with facility design issues. The Disposal Facility Design Working Group and this document have been concerned with the overall design of near-surface disposal facilities at a broad, conceptual level, rather than with, for example, details of the precise engineering design of a particular waste package or engineered barrier.

3.2 ACTIVITIES

At the first project Plenary Meeting held in March 2009, the Working Group (Appendix 1) decided to focus its work on the processes of designing and upgrading near-surface radioactive waste disposal facilities using the safety case. The approach adopted involved:

- **A review of past and current practice on disposal facility design.** This looked at examples and experiences related to the development of facility design and the safety case for a wide range of near-surface facilities types. Information was gathered from members of the Disposal Facility Design Working Group, from other PRISM project participants, and from relevant publications. Working group participants provided a range of presentations and papers as discussed below.
- **Identifying lessons regarding good practice in facility design and the use of the safety case to assist this process.** The Working Group identified and considered the many factors that affect disposal facility design (see below), and sought to:

- Describe expectations of facility design information at different stages of facility development.
- Describe relationships between facility and engineered barrier system (EBS) design and the safety case.
- Discuss optimisation as it applies to disposal facility design.

3.3 INFORMATION GATHERING

At the first PRISM project plenary meeting in March 2009, the disposal facility design working group developed some brief terms of reference for the process of data gathering to serve as a guide for the contents of presentations and associated papers. It envisaged that for each facility considered presentations and papers would address the following:

- The System Description and Context - A general description of facility and its development history, e.g:
    - Brief information on the site and the waste characteristics, and on the facility design and any design options considered.
    - Any important influences of regulations or related guidance on the facility design.
- The Safety Strategy and related design philosophy, e.g:
    - The emphasis given to isolation, to containment, to passive systems, to robustness, to defence in depth, etc
- The reasons for the inclusion and design of each engineered component (e.g., the waste package, backfill, walls, cap, drains).
- The functions assigned to the engineered components, noting whether these functions were explicitly identified in the safety case and supporting safety assessment for the facility.
- The history of any design changes and the reasons for any changes (including the use of the safety case and supporting safety assessment in identifying the need for changes or for justifying changes).
- A description of the treatment of the engineered barriers and of engineered barrier degradation in the safety the safety case and supporting safety assessment.

During the second PRISM project plenary meeting in October 2010, the disposal facility design working group held a series of workshop style sessions comprising presentations on disposal facility design and the safety case, and discussions of key issues and lessons learnt.

At the third PRISM Plenary Meeting, held during 31 October to 4 November 2011, the working group reviewed the treatment of disposal facility design in several recently prepared IAEA documents (e.g. IAEA 2011) identified and discussed key safety case arguments with respect to facility design, and considered how these arguments might develop over time during the lifecycle of a near-surface disposal facility.

The fourth and final PRISM Plenary Meeting was held during 3 to 7 December 2012, at which the working group discussed and completed its draft report.

Section 4 of this report identifies and discusses the various factors that influence disposal facility design and, based on these, presents examples of the types of high-level arguments that may be made in the safety case. Section 5 presents a series of practical examples of the influence of different factors on disposal facility design. The examples allow discussion of experience in near-surface waste disposal from which lessons may be learnt relating to good practice in facility design and the use of the safety case, at different stages of facility development, operation and closure. Section 6 presents the conclusions from the working group.

4 DISPOSAL FACILITY DESIGN AND THE SAFETY CASE

4.1 IAEA SAFETY REQUIREMENTS ON DISPOSAL FACILITY DESIGN

The IAEA has established a range of Safety Fundamentals, Safety Requirements and Safety Guides, which it encourages Members States to apply by means of their regulatory provisions for nuclear and radiation safety. In particular, Specific Safety Requirement SSR-5 (IAEA 2011) sets out the Requirements for the disposal of radioactive waste.

According to SSR-5, the specific aims of disposal are:

- *'To contain the waste;*
- *To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste;*
- *To inhibit, reduce and delay the migration of radionuclides at any time from the waste to the accessible biosphere;*
- *To ensure that the amounts of radionuclides reaching the accessible biosphere due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times.*

The optimization of protection (that is, the process of determining measures for protection and safety to make exposures, and the probability and magnitude of potential exposures, 'As Low As Reasonably Achievable (ALARA), economic and social factors being taken into account' is considered in the design of the disposal facility and in the planning of all operations.

The safety objective is to site, design, construct, operate and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long term will not exceed the dose constraints or risk constraints that were used as design criteria. To comply with the dose limit, a disposal facility is so designed that the calculated dose or risk to the representative person who might be exposed in the future as a result of possible natural processes affecting the disposal facility does not exceed a dose constraint of 0.3 mSv in a year or a risk constraint of the order of 10^{-5} per year. If annual doses in the range 1–20 mSv are indicated, then reasonable efforts are warranted at the stage of development of the facility to reduce the probability of intrusion or to limit its consequences'.

Key aspects of the IAEA's Specific Safety Requirements on the disposal of solid radioactive wastes with respect to disposal facility design and the safety case include:

Requirement 4: **Importance of safety in the process of development and operation of a disposal facility**

'*Throughout the process of development and operation of a disposal facility for radioactive waste, an understanding of the relevance and the implications for safety of the available options for the facility shall be developed by the operator. This is for the purpose of providing an optimized level of safety in the operational stage and after closure'*.

Requirement 7: **Multiple safety functions**

'The host environment shall be selected, the engineered barriers of the disposal facility shall be designed and the facility shall be operated to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system. The performance of these physical barriers shall be achieved by means of diverse physical and chemical processes together with various operational controls. The capability of the individual barriers and controls together with that of the overall disposal system to perform as assumed in the safety case shall be demonstrated. The overall performance of the disposal system shall not be unduly dependent on a single safety function'.

Requirement 8: **Containment of radioactive waste**

'The engineered barriers, including the waste form and packaging, shall be designed, and the host environment shall be selected, so as to provide containment of the radionuclides associated with the waste. Containment shall be provided until radioactive decay has significantly reduced the hazard posed by the waste. In addition, in the case of heat generating waste, containment shall be provided while the waste is still producing heat energy in amounts that could adversely affect the performance of the disposal system'.

Requirement 9: **Isolation of radioactive waste**

'*The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high-level waste. In so doing, consideration shall be given to both the natural evolution of the disposal system and events causing disturbance of the facility*'.

Requirement 11: **Step by step development and evaluation of disposal facilities**

'Disposal facilities for radioactive waste shall be developed, operated and closed in a series of steps. Each of these steps shall be supported, as necessary, by iterative evaluations of the site, of the options for design, construction, operation and management, and of the performance and safety of the disposal system'.

Requirement 16: **Design of a disposal facility**

'The disposal facility and its engineered barriers shall be designed to contain the waste with its associated hazard, to be physically and chemically compatible with the host geological formation and/or surface environment, and to provide safety features after closure that complement those features afforded by the host environment. The facility and its engineered barriers shall be designed to provide safety during the operational period.

Requirements are also established for ensuring that there is adequate defence in depth, so that safety is not unduly dependent on a single element of the disposal facility, such as the waste package; or a single control measure, such as verification of the inventory of waste packages; or the fulfilment of a single safety function, such as by containment of radionuclides or retardation of migration; or a single administrative procedure, such as a procedure for site access control or for maintenance of the facility.

Adequate defence in depth has to be ensured by demonstrating that there are multiple safety functions, that the fulfilment of individual safety functions is robust and that the performance of the various physical components of the disposal system and the safety functions they fulfil can be relied upon, as assumed in the safety case and supporting safety assessment. It is the responsibility of the operator to demonstrate fulfilment of the following design requirements to the satisfaction of the regulatory body'.

The following sections discuss the ways in which the key aspects of the requirements may be included in the safety case for disposal and implemented in a practical way during the disposal facility lifecycle.

4.2 SAFETY CASE ARGUMENTS ON DISPOSAL FACILITY DESIGN

When developing a safety case it is possible and good practice to develop a set of safety case arguments that if sufficiently supported combine to give confidence in the safety and acceptability of the disposal facility (e.g. IAEA 2012; ONDRAF/NIRAS 2009).

These safety case arguments can be very general in nature, an example being the statement that the proposed disposal system will provide an adequate level of passive long-term safety if implemented according to design specifications. They can also be more specific, such as the statement that a certain disposal facility barrier of a specific design and in a specific physical and chemical environment will remain intact and provide a specified low hydraulic conductivity for a given minimum period of time.

Some arguments, particularly those that are more general in nature and are, for example, a direct translation of the safety concept, can be formulated early in the programme, while other, more detailed statements gradually emerge as the programme progresses, the safety concept and the design become better defined and more firmly established, and the assessment basis in general is further developed. Safety case arguments are, thus, initially at least, developed and structured in a top-down manner, starting with the most general (high-level) statements and progressing to increasingly specific (lower-level) statements (for example, arguments regarding the required performance of specific system components).

Working group discussions showed that in addition to the high-level Safety Requirements identified above, disposal facility design may be affected by a wide range of factors including:

- Relevant policy and strategy on the management of radioactive wastes.
- National and international safety requirements and the strategy for providing isolation, containment, passive safety, robustness, optimisation, etc (i.e., the Safety Strategy).
- Stakeholder views.
  - Public, local communities, scientific community, others.
- Regulations and regulatory guidance regarding:
  - Radiological and conventional safety, as well as planning/construction related regulations and guidance.
- Environmental impacts and assessments.
- The waste inventory, waste types and waste characteristics.
- Site characteristics.
- Best practice, past practice / operational experience.
- Availability and understanding of barrier materials, construction and waste disposal technologies and engineered barrier system performance.
- Engineering feasibility.
- Project timescales and flexibility.
- Costs and benefits of different design options.
- Monitoring requirements, desires and plans.
- Safety assessment assumptions and results regarding:
  - Engineered barrier performance and degradation.
  - Measures to reduce the probability of human intrusion.
- Waste Acceptance Criteria (WAC).

Based on the Safety Requirements and these other potentially important factors, a set of potential safety case arguments on disposal facility design is set out in Table 4.1. These are generic examples of the types of argument that may be relevant to a near-surface disposal facility and not all arguments will be relevant to all facilities. Such arguments would need to be developed on a case by case basis.

All safety case arguments should be properly supported, or ‘underpinned’, with quality assured and peer reviewed assessments, analyses, evidence and data. Safety case arguments generally begin as unsubstantiated or poorly-substantiated statements or aspirations, but develop into increasingly well-substantiated claims as the design and implementation procedures are developed and optimised, and the evidence, arguments and analyses that support each statement are acquired or progressively developed.

Table 4.1 Example Safety Case Arguments on Disposal Facility Design

1) The disposal facility design has been developed taking account of the volumes, types and characteristics (e.g. the chemical and radiological properties) of wastes expected to require disposal.
2) A design for the disposal facility has been developed that, in conjunction with other limits and controls (e.g. waste acceptance criteria and institutional controls) will provide levels of safety that are acceptable and as low as reasonably achievable (ALARA).
3) The disposal facility has been designed in accordance with appropriate management and quality systems.
4) The disposal facility design has been developed in accordance with relevant policies and strategies, regulations and guidance, and the process followed has addressed stakeholder views.
5) The disposal facility design process has included applying lessons from operational experience at similar relevant facilities, and identifying and adopting relevant best practice and technology.
6) The disposal facility design has been developed at a level of detail that is appropriate for the current stage of facility development.
7) The disposal facility design reflects relevant site-specific information.
8) The disposal facility design has been developed taking into account environmental impacts associated with its construction (e.g. related to materials extraction / mining, and transport) and operation.
9) The disposal facility design incorporates economically effective (e.g. locally available) materials that are sufficiently characterised and whose behaviour, including long-term degradation, is well understood.
10) The disposal facility design allows for relevant monitoring activities to be conducted, but provides safety in a passive way. Future generations cannot be assumed to take actions to maintain or monitor the disposal facility after the period of active institutional control. Passive institutional controls cannot necessarily be assumed to be effective.
11) The potential radiological and environmental impacts of the conceptual, 'as designed' or 'as built' disposal facility have been assessed within the safety case and shown to be acceptable.
12) The disposal facility design allows for ease of operations (e.g. for waste emplacement, for reversibility) and provides acceptable levels of operator safety.
13) The disposal facility design has been developed as part of the iterative process of safety case development.
14) The disposal facility has been constructed and operated consistent with the assumptions made in the safety case regarding its design.
15) The disposal facility has been sited and designed to reduce the likelihood and/or consequences of relevant potentially disruptive events and scenarios (e.g. intrusion and other disruptive events).
16) Provision has been made for regular reviews and updates of the safety case and the facility design.
17) Appropriate records have been made of the reasons for adopting the facility design and for any facility design modifications. These records provide evidence of design optimisation, information on the history of construction, and could be included as part of the records kept as passive institutional controls.
18) Opportunities will be taken to further improve / optimise the design and the safety of the disposal facility throughout the period until the end of active institutional control.

While safety case arguments are initially developed from the top-down, they tend to be assessed in terms of the level of support available from the bottom-up, beginning with lower-level, more detailed statements, and progressing to higher-level, broader statements (Figure 4.1).

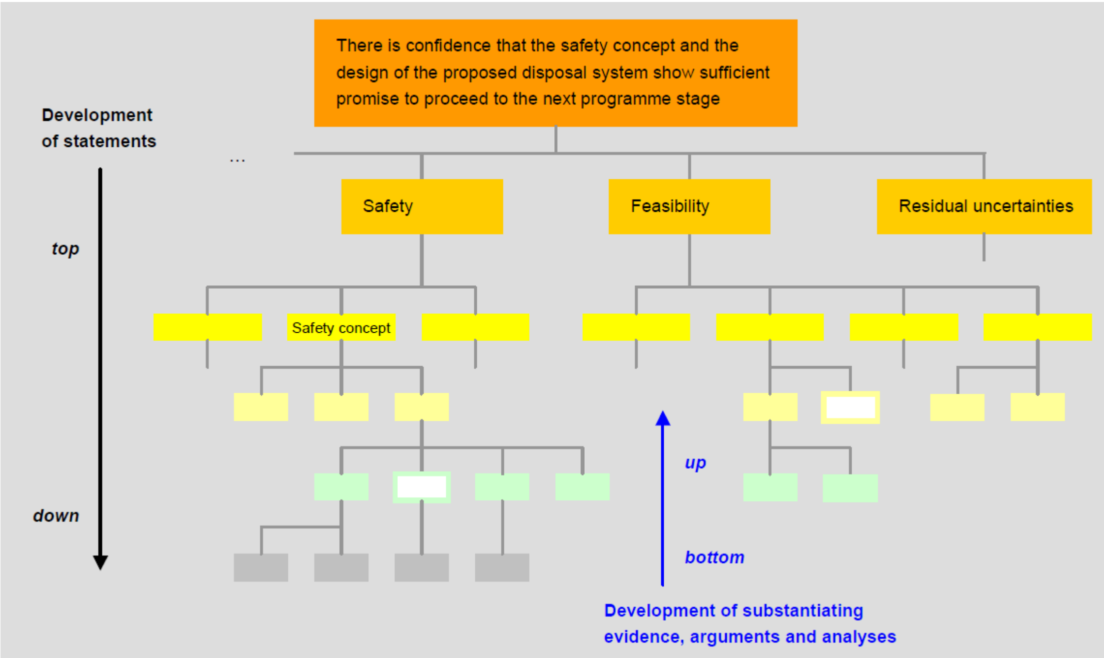

Figure 4.1 The bottom-up assessment of the level of support for safety and feasibility statements. Low-level statements directly supported by phenomenological evidence from the assessment basis are shown in grey (ONDRAF/NIRAS 2009).

The progressive gathering of information, data, and evidence, and its integration within the safety case is an essential part for developing sufficient confidence in the safety of waste disposal plans and managing the operation of waste disposal facilities.

4.3 EVOLUTION OF SAFETY CASE ARGUMENTS ON DESIGN

This section considers what might be expected in terms of facility design at different stages in facility development and implementation.

The various stages and decision-steps in a typical programme for the development and implementation of a near-surface disposal facility have been described by PRISM Working Group 1 (Figure 4.1). The lower part of Figure 4.2 illustrates the general, or typical, sequence of steps in facility development. A detailed discussion of the sequence of steps is provided in the PRISM Overview Report. The annotations in the upper part of Figure 4.1 indicates the approximate timing of various facility design and related activities, based on the experiences of the design working group.

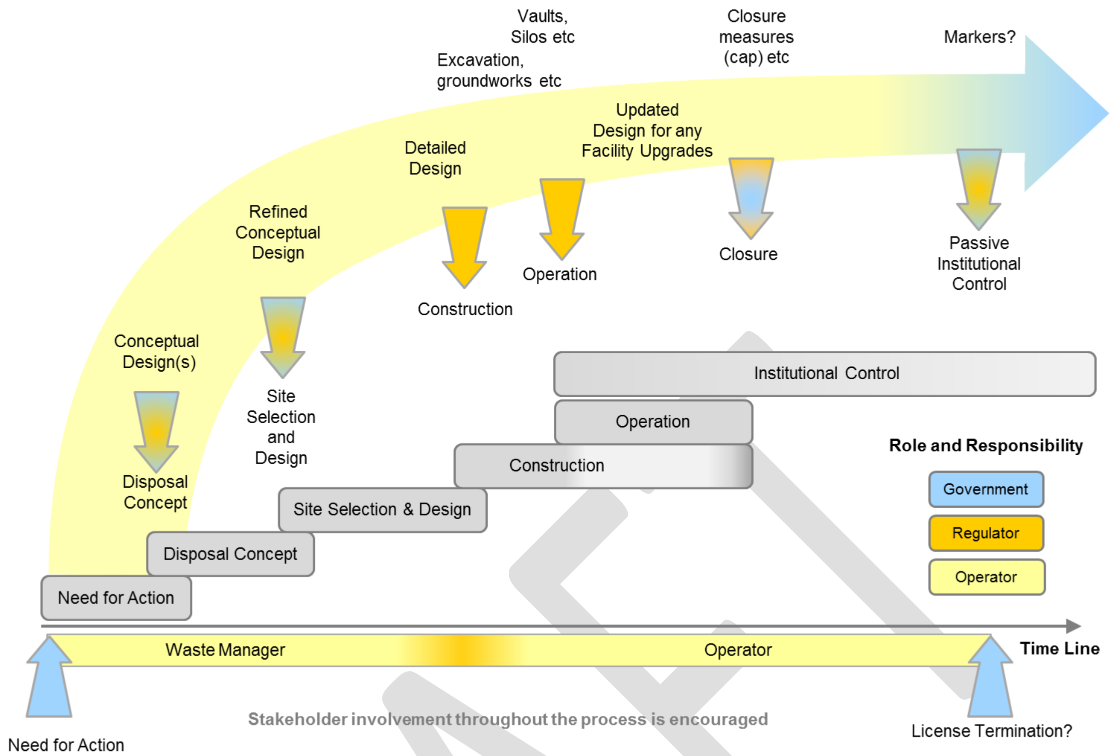

Figure 4.2 Stages and decision steps in disposal facility development, and the approximate timing of disposal facility design and related activities.

In general terms, facility design information can be expected to develop with time from an outline or conceptual level, to being increasingly more detailed in designs ready for construction and facility closure. Figure 4.3 illustrates such a progression.

Early in a waste disposal programme, it should be possible to identify the general requirements for waste disposal as defined collectively by the various stakeholders (e.g., the government, the waste owners, the prospective facility operators, the regulators and relevant populations). It is then possible to outline one or more disposal system concepts, to make preliminary assessments of potential disposal system safety, and from these to derive preliminary, or generic, waste acceptance criteria. Some programmes conduct a preliminary or strategic Environmental Impact Assessment (EIA) in the early stages of considering radioactive waste disposal. The precise requirements for EIA are country-specific.

Stage	Requirements	Design	Safety Case & Assessments
Disposal Concept	Stakeholder Requirements, Waste Volumes and Main Characteristics, Preliminary Waste Acceptance Criteria	Disposal System Concept	Strategic Environmental Impact Assessment (EIA), Preliminary Safety Case & Assessment
Site Selection and Design	Generic Site(s), Generic Concept (s) and Design Requirements	Generic Systems and Subsystem Designs	Generic Safety Case and Feasibility Assessments
	Site-Specific Concept and Design Requirements	Site-Specific Design	Site and Concept-Specific EIA, Safety Case and Feasibility Assessments
Construction	Detailed Design Requirements (particularly for pre-closure components)	Detailed Engineering Design	Detailed Safety Case and Assessment to Support Construction Licence
Operation	Constraints Imposed by Wastes Received and Operational History	Initial Optimised Design and Subsequent Refinements	Detailed Operational and Post-Closure Assessments to Support Operating Licence & Periodic Re-Assessments
Closure	Stakeholder and Technical Design Requirements for Closure Components	Detailed Engineering Design for Closure Components	Detailed Post-Closure Safety Case and Assessment to Support Closure Decision

Time

Figure 4.3 The progression of design requirements, designs, safety cases and assessments with time during disposal facility development.

During the facility design and implementation process, different levels of design requirements will exist and these will need to be managed in a structured fashion so that they are met using a technically feasible design. High-level regulatory requirements, such as the potential need for monitoring, are often expressed by stakeholders or may be included within legislation or other statutory documents. Other high-level requirements may derive from the owners of the waste. At later stages, lower-level requirements, or constraints, may derive, for example, from the characteristics of the site, the waste or the materials of the engineered barrier system, or stem from a desire to simplify the assessment of disposal system performance. Requirements management systems (e.g., NEA 2004) can be used to link between the middle two columns in Figure 4.3 and provide structured approaches for recording and managing decisions on disposal facility design over time. This may be important because the justification for the current design will often lie partly in the records of previous comparisons and decisions made regarding possible design alternatives.

The 'safety functions' of the various engineered and natural components that comprise the disposal concept may be identified and used in safety cases as a means of linking disposal concepts and designs to safety assessments (i.e. linking between the two columns on the right in Figure 4.3). Safety functions identify the role that each key component of the facility design plays in contributing to system safety (e.g., SKB 2008; 2011). For example, a safety function for a facility cap might, in general terms, be specified such that it will limit water inflow to the wastes. Safety functions can also be specified in the form of more quantitative requirements and parameters (e.g., the hydraulic conductivity of the facility cap to water at the time of its construction shall be less than 10^{-9} m/s) that can then be assessed using scientific knowledge of materials behaviour and the likely processes of cap degradation, and represented in safety assessment (e.g. US NRC 2000). Recent safety cases and safety assessments for waste disposal in Belgium and Sweden have made particular use of safety functions (e.g. Van De Velde 2011).

After the disposal concept has been identified, many disposal programmes pass through a phase of siting and site selection. This phase typically includes working with information on one or more potential or hypothetical sites. This may involve considering system and design requirements in more detail, but still at a generic level, and evaluating the potential safety and feasibility of disposal at such locations or sites. The assessments made at this stage are often based on generic (e.g. literature) data, rather than on site-specific data.

Once a specific site has been chosen, it becomes possible to gather, and gradually introduce more site-specific data to the assessments. It also becomes possible to identify site-specific design requirements, and to develop and select particular design options that are best suited to the characteristics of the site. For example, it might be decided to adopt a design that minimises contact between the disposed wastes and water. This might be achieved by locating the disposal trenches or vaults above the water table, and providing a relatively less permeable facility cap as compared to the permeability of the base of the disposal facility (e.g. LLWR 2011a; Viršek 2010).

Such strategic design decisions and design choices will need to be made within any disposal programme. This is because it is not feasible or economic to continue to research many alternative design options in great detail, and because, particularly at operating facilities, there is a need to take decisions and continue waste disposal (EC/NEA 2010).

Strategic design decisions (e.g. between alternative disposal concepts) can be aided by using structured options appraisals, sometimes involving multi-attribute decision-analysis (MADA) approaches (e.g. UKAEA 2004). Such approaches consider the wide range of factors that may influence each choice and help to make the reasons for each choice more transparent. These options appraisals can also be used to include a wider range of groups in the decision-making process, thereby enhance community involvement and confidence in the process and the direction being taken.

To support a decision for facility construction, it is necessary to develop detailed design requirements and engineering designs. Such designs should be developed for all repository components, even though the construction of some (e.g. the final cap) might not occur for several decades. Attention should be given, for example, to the design of drainage systems, monitoring systems and methods for waste emplacement and, if required, retrieval.

The amount of detail required at the pre-construction stage will depend on the regulatory context for the disposal programme. Some national licencing procedures involve just a single step in which permission is given for facility construction and operation (i.e. waste disposal). Other national programmes have two or more steps in the licencing process (e.g. a permission step for facility construction, one for facility operation, and one for closure). In general, the fewer steps in the process the more stringent the information requirements are likely to be at early stages in the process.

As facility operation is approached, it becomes increasingly possible and necessary to consider operational safety in detail. Trials of disposal facility engineering components (e.g. caps) may also be conducted to gather data on their performance and investigate the feasibility of their construction using the chosen materials.

As more data and information becomes available it is possible to begin the process of optimising[1] the selected design concept. The safety case and safety assessment provide the single most important vehicle for integrating all of the information and allowing its relative importance to be understood. In order to inform design decisions in the best way possible, safety assessments should be as realistic as possible rather than being based on highly conservative assumptions and approaches.

As disposal facility operation is approached and commenced, safety assessments should be used together with other relevant information to derive and apply waste acceptance criteria. It is essential that well-defined waste acceptance criteria are in place before operation begins (see PRISM Working Group 3).

Appropriate construction, operating and monitoring activities are undertaken, and records of these activities should be kept. Safety assessments should be conducted that reflect such records and monitoring data, so that the safety case can be used to control the operation and management of the facility. For example, the design (or other limits and controls) may be revised to account for new data and information in the safety case as it is updated.

At periodic intervals the safety case should be updated and the safety of the facility and its mode of operation reviewed. This provides various opportunities, for example, to improve the safety of previously emplaced wastes, to extend the facility, and / or to accept new waste streams (e.g., IAEA 2005; LLWR 2011a, b; Ormai 2011). It is common for near-surface disposal facilities to operate for several decades and during this time it may be necessary to re-assess the safety of older disposals, such as those made under previous regulations and standards, and to consider different options for their future management. Again, MADA approaches may be used in considering different options (LLWR 2011b).

This cycle of review and disposal facility ‘upgrading’ is part of the overall process of disposal facility management and optimisation. The approach comprises a continual process of iterative optimisation that involves understanding the requirements on the disposal system, its design and components and their behaviour, considering the

[1] The term optimisation is used here in a broad sense that implies consideration of a wide range of technical, radiological and socio-economic factors.

various processes that can affect disposal system performance, undertaking various modelling and safety assessment studies, updating the safety case to reflect new information (e.g., from operations and monitoring programmes), and refining the various controls (engineering measures, waste acceptance criteria, institutional controls – see below) in a way that provides for safety. This cycle is illustrated in Figure 4.4. The significant amount of practical implementation experience that exists in near-surface disposal shows that using the safety case to work through such feedback cycles is an important part of facility management.

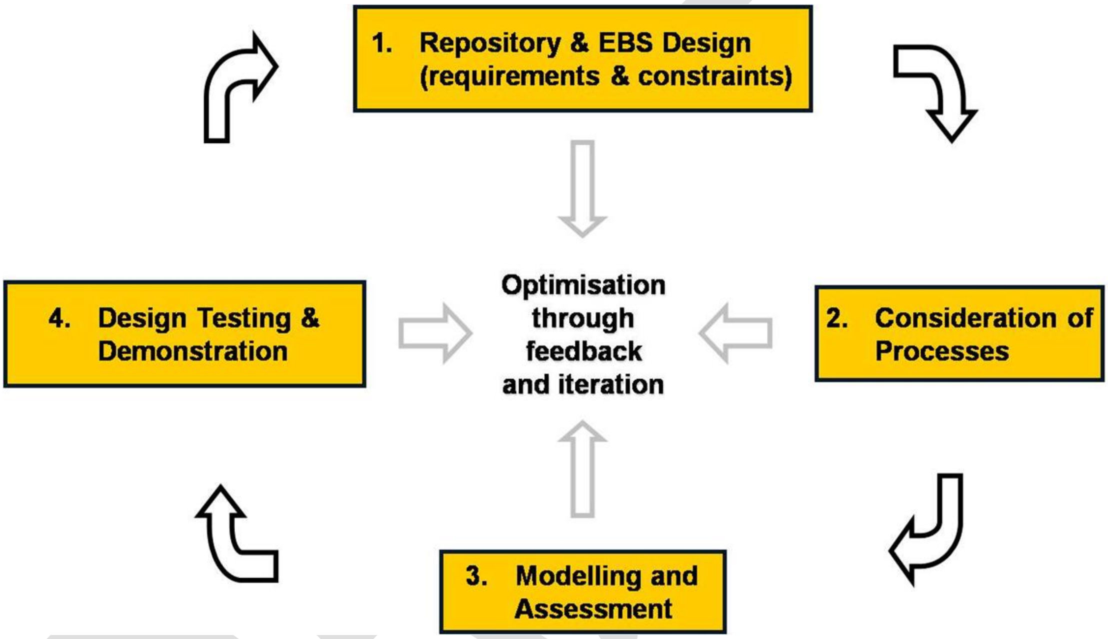

Figure 4.4 Iterative optimisation (design refinement) cycle (EC/NEA 2010)

At some point a decision will need to be made to close the disposal facility and, as needed, enter a phase of institutional control. At this stage the main points of relevance to facility design will be the design of, and methods for the implementation of, the closure engineering, together with any engineering measures that might be required to reduce the probability and or consequences of future human intrusion. It may also be important to consider any measures required for on-going monitoring of the performance of the closure components and of the disposal system.

The closure engineering will depend on the type of facility under consideration, but for typical trench or vault type near-surface disposal facilities will usually include a final facility cap. For deeper facilities, for example, those involving caverns or silos, the closure engineering is likely to include seals and backfills. Measures for reducing the probability and or consequences of future human intrusion might include physical barriers such as the placement of concrete slabs over the wastes or increasing the thickness of the facility cap, or other types of control, such as the placement of markers at the facility and or the lodging of records in local and national archives. Plans may also be needed for the decommissioning of features such as boreholes and drains. Detailed engineering designs will be needed for all of the physical closure components and it is expected that the regulatory authorities will also require a rigorous and detailed safety case and safety assessment to support the closure decision.

An important activity will be the recording and archiving of data and information on the disposal facility, including information such as the location of the wastes and their characteristics, the design of the facility as constructed.

IAEA (2011) indicates that near-surface disposal facilities are generally designed on the assumption that institutional control has to remain in force for a period of time. At different stages in the lifecycle of a near-surface disposal facility, safety will rely to a varying degree on active and passive institutional controls. Active and passive controls may be put in place during facility design, construction, operation and closure.

It is often assumed that for all but the smallest facilities containing only short-lived, low-hazard wastes, active control of the disposal facility site (e.g., access restrictions, surveillance) will be maintained for some time after closure. It cannot, however, be assumed that active institutional controls measures will persist and be effective indefinitely, and so it is commonly assumed that, in the longer term, active controls will cease. Thereafter passive institutional controls (e.g. engineered barriers that reduce the probability of human intrusion, archived records and long-term memory of the facility) may help to provide assurance of continued safety.

Although the safety case and safety assessment cannot rely on an assumption of indefinite effective active institutional control, in practice many near-surface disposal facilities contain long-lived wastes and are likely to be kept under continuing institutional control. The Centre de la Manche in France is an example of a closed near-surface disposal facility that is being kept under active institutional control (Chino et al. 1999; Tichauer 2010). The status of such facilities should be reviewed periodically and in some cases it may be appropriate for control to be transferred from the original operator to the state.

5 DISPOSAL FACILITY DESIGN: EXAMPLES AND EXPERIENCES

The disposal facility design working group received a considerable number of presentations and papers covering facility design and the safety case for the following disposal facilities and programmes (see Appendix 2):

- Various small trench and mound-type facilities for mining and uranium ore processing wastes in western and northern Australia
- Preliminary designs for an engineered near-surface disposal facility for LILW at Dessel, Belgium.
- LLW management at Port Hope and neighbouring sites, Canada.
- LLW management at the Centre de la Manche and the Centre l'Aube, France.
- LLW disposal at the Püspökszilágy facility, Hungary.
- LLW disposal in Israel.
- Disposal facility siting experiences and LILW disposal in South Korea.
- The Maišiagala Radon-type repository, Lithuania.
- Surface storage facility design, the Netherlands.
- A Radon-type disposal facility, Russia
- Design and development of the Mochovce Repository, Slovakia.
- A silo concept for a LILW repository in Slovenia.
- The El'Cabril Disposal Facilities, Spain.
- Several shallow land disposal facilities for radioactive waste from nuclear facilities in Sweden.
- Optimising the design of the Low-Level Waste Repository (LLWR), UK.

This section highlights and discusses key points that can be drawn from the presentations and papers regarding safety case arguments and the influence of various factors on disposal facility design. A few of these issues, topics or components relate directly to quantitative safety assessment but, the majority, relate to more qualitative components of the safety case.

5.1 INFLUENCE OF NATIONAL AND LOCAL POLICY AND APPROACHES

A common starting point for the design of new near-surface radioactive waste disposal facilities is a decision to proceed with disposal and/or the identification of a need (or a requirement) to dispose of certain wastes or waste types with known, or approximately known, characteristics, activities and volumes. These decisions or requirements may be established by national government in policy and/or developed by those responsible for waste management, in conjunction with various other stakeholders and the regulators. These decisions and requirements are also likely to have a strong influence on proposals and decisions to extend existing disposal facilities so that they can accommodate additional wastes. A considerable number of the disposal programmes and facilities considered by the working group are actively involved in planning, assessing and implementing facility extensions (e.g. Mochovce, Slovakia; El Cabril, Spain; Olkiluoto, Finland; Forsmark, Sweden; LLWR, UK). Some of these examples are discussed in more detail below, but the point to note is that national and local policies on long-term waste management may have a very significant effect on the size and, therefore, on the design of a particular disposal facility.

5.2 INFLUENCE OF SAFETY REQUIREMENTS - THE OVERALL APPROACH TO PROVIDING SAFETY

As discussed in Section 4.1, the IAEA has established a range of Safety Fundamentals, Safety Requirements and Safety Guides, which it encourages Members States to apply by means of their regulatory provisions for nuclear and radiation safety (IAEA 2011). Key aspects of the IAEA's Specific Safety Requirements on the disposal of solid radioactive wastes are the provision of waste **containment** and **isolation** (IAEA 2011).

According to IAEA (2011):

- ***'Containment of radioactive waste implies designing the disposal facility to avoid or minimise the release of radionuclides.'***

- ***'The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high level waste.'***

It is becoming common practice for waste management organisations to develop and formally document their overall approach to the provision of waste containment and isolation, and of safety in what is variously referred to as a **safety strategy** or **safety concept** (e.g., ONDRAF/NIRAS 2007; Environment Agency et al. 2009; LLW Repository Ltd 2011).

According Environment Agency et al. (2009), the safety strategy should present '*a top level description of the fundamental approach taken to demonstrate the environmental safety of the disposal system. It should include a clear outline of the key environmental safety arguments and say how the major lines of reasoning and underpinning evidence support these arguments. The strategy should explain, for example, how the chosen site, design for passive safety and multiple barriers each contribute to environmental safety*.'

The Belgian safety concept for a near-surface disposal system for Category A LLW is realised through (ONDRAF/NIRAS 2007):

- '*Management principles – an open management process, staff safety culture and training, internal and external reviewing;*
- *A rigorous procedure of waste acceptance, to ensure appropriate limitation of the radioactive source, based on waste acceptance criteria, qualification of waste packages, production and measurement facilities, processes and characterisation methodologies, and acceptance of waste;*
- *Conditions on the selected site to ensure its technical suitability;*
- *Active measures (monitoring and active surveillance) to ensure protection of humans and the environment during an initial period after completion of waste emplacement;*
- *Development and implementation of an engineered barrier design to fulfil the required key design principles (i.e. robust and demonstrable safety, defence in depth, passive safety, best available techniques* [BAT]*) and passive safety functions'.*

The safety strategy, or safety concept is, thus, broad and addresses a range of IAEA Safety Requirements (IAEA 2011) and safety case components, including, isolation, containment, passive safety, robustness, monitoring, and demonstration of the use of best available techniques, optimisation and compliance with applicable dose constraints, risk targets etc. Discussions of the components of the safety case are also given in the report from PRISM Working Group 1, however, **the provision of many of the safety case components rests significantly on the facility design process. The facility design process needs, therefore, to be progressed at the same time as, and in parallel intimate contact with safety case development**.

5.3 INFLUENCE OF STAKEHOLDERS ON FACILITY DESIGN

Stakeholders may have a strong influence on disposal facility siting, acceptance and design. An interesting example can be taken from the experience of working to find acceptable waste management solutions for some long-lived LLW derived as a result of cleaning up contaminated ground from many small locations in and around the town of Port Hope in Canada (Walker 2011).

The LLW at Port Hope derives from soil that was contaminated during radium and uranium refining activities during the period from the 1930s to the 1970s. Despite the conduct of various environmental and epidemiological studies that showed that no adverse health effects have occurred, or are likely to occur, as a result of the contamination, there was concern that the presence of the contamination was affecting the perception and economic health of the town.

The community asked the Canadian federal government to fulfil its commitment to clean up historic industrial wastes. The Port Hope Area Initiative was therefore set up, and is being conducted on behalf of the Canadian federal government (Natural Resources Canada) by AECL.

The major benefit of the clean-up is seen as a better socio-economic and natural environment for future generations. For the individual residents, the benefit will be peace of mind, achieved through the removal of questions and concerns regarding low-level radioactive waste and contaminated soils on their property or elsewhere, and the knowledge that the material is being managed safely for many generations.

Consultation with the public, and other interested stakeholders, and First Nations (Curve Lake, Hiawatha and Alderville Councils) has been a key part of the Port Hope Project.

Each municipality formed a local citizens' committee to develop a conceptual proposal for cleaning up and managing the waste. The Canadian government provided funding to support the work of these committees, including the hiring of external consultants.

Given the history of contamination in the area, the issue of trust was a paramount consideration. In the mid-1990s a proposal for an underground mined cavern type disposal facility on the Port Hope waterfront had been developed, but this received significant public opposition related to the difficulty that the public would have in observing and monitoring the performance of an underground disposal facility.

Later initiatives have focused on 'long-term management' (nominally 500 years) rather than 'disposal', and placed emphasis on facilities that can be readily monitored, maintained and repaired as necessary, and where the waste could be retrievable in the event that this should be desirable in the future.

Port Hope residents, the Municipality and other stakeholders were directly involved in coming to these proposals, including major decisions regarding alternative means of conducting the project, and the identification of transportation routes and clean-up criteria. The proposals include aspects that are important to the local communities: the facilities would be above ground (a refinement of the engineered burial mound concept), actively monitored, and engineered to permit passive recreational end use on their surface (e.g., low-maintenance walking trails).

The concept arrived at involves the construction of a new long-term waste management facility in the form of an above-ground mound with a multi-layer cover, or cap. This would be constructed at an existing closed waste site and adjacent property outside the town, close to a major highway (Figure 5.1).

Figure 5.1 Conceptual design for a new above ground, mound type waste management facility for long-lived LLW near Port Hope, Canada.

The mound will be highly visible and it is believed that this will help in demonstrating that the contamination and the waste have been located and removed from the town for appropriate safe management including monitoring and if desired in future retrieval.

The example shows that that **public participation can have profound effects upon the design of a waste management facility**. The outcome of the consultative process at Port Hope has arrived at a waste management solution that is acceptable to the local population, but which will require long-term maintenance and monitoring of the facility for hundreds of years or possibly longer, given the long-lived nature of the wastes. The Canadian experience suggests that **as a general principle, as long as safety can be demonstrated, community concerns should be placed on an equal footing with technical factors**.

Other examples can be cited of instances in which stakeholders have influenced disposal facility designs. The visual impact of the Low-Level Waste Repository (LLWR) in Cumbria, UK is an issue of concern to some local residents. This has been considered by the regulators and operators of the LLWR and adjustments made to operating practices (e.g., waste stacking heights) and the profiling of the final cap for the facility (LLW Repository Ltd 2011a, b).

5.4 USE OF 'BEST PRACTICE' AND EXPERIENCE IN FACILITY DESIGN

An increasing number of international treaties and national regulations and guidance require explicitly, or implicitly, the application to radioactive waste management and disposal of '*best practice'*, '*best available techniques*' (BAT), '*best practicable means'* (BPM), '*best environmental practice'* (BEP) '*state of the art practices'* or similar. The general intent of these terms is essentially the same; that is the operator should apply the 'best' practice in order to reduce impacts (e.g. releases from the barrier system, doses, risks), taking account of a wide range of factors, including societal issues and costs. There is also a strong emphasis on the need to demonstrate learning from previous operational practices and, where appropriate, make improvements.

Relevant international treaties and directives from which these terms derive include the OSPAR Treaty, the European Commission (EC) Basic Safety Standards Directive, the EC Directive on Integrated Pollution Prevention and Control, and the EC Framework Directive on Waste. To take one example, the EU Directive on integrated pollution prevention and control (EC 1996) defines Best Available Techniques (BAT) as follows:

- *'**'Best available techniques'** shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole:*

- ***'Techniques'** shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned,*

- ***'Available'** techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator,*

- ***'Best'** shall mean most effective in achieving a high general level of protection of the environment as a whole.'*

The IAEA Draft Standard on near surface disposal of radioactive waste, DS356, (IAEA in prep) includes the following guidance:

- *'facility design for operational safety should include both active and passive systems and **should rely on state of the art radiological and industrial safety practic**es, analogous with existing nuclear facilities.'*

- *'The safety of activities associated with facility construction should consider the possibly concurrent activities of construction and waste emplacement, and* ***should reflect a combination of the best radiological, industrial and civil engineering safety practices****.'*

While the guidance in DS356 (IAEA in prep) refers to the pre-operational and operational phases of a waste disposal facility lifecycle, other documents, including formal regulations, apply concepts such as best practice or BAT to the full operational lifecycle of the facility and this includes taking account of potential future impacts that might occur in the post-closure phase (e.g. SSI 1998; SSI 2005, Environment Agency et al. 2009).

For example, Environment Agency et al. (2009) states:

'For the period of operation of disposal sites for LLW, the effective dose to a representative member of the critical group should not exceed the single source-related dose constraint…, and shall be reduced below this level to the extent practicable through the use of the Best Practicable Means (BPM) principle to ensure that doses to people are 'as low as reasonably achievable' (ALARA), economic and social factors being taken into account. This dose constraint also applies to the period following cessation of operations, during which the site would remain under management control, and when monitoring would be undertaken.'

It can be seen that there is increasing focus on the need for operators to demonstrate that the disposal system and its impacts have been optimised by identifying and applying best practices or similar (e.g. BAT). It is also recognised that in some cases (e.g., high-level waste disposal) certain aspects of technology for waste disposal need further development and may not yet be regarded as available.

Regulations or regulatory guidance that adopt approaches of requiring best practice or similar tend to be non-prescriptive (e.g. in terms of precisely which technologies should be applied) and are therefore flexible. They can also have an enduring strength because they typically require operators continuously to review their operations against whatever represents best practice at the time and, if necessary, upgrade their operations.

The Disposal Facility Design Working Group discussed many examples of situations in which disposal practices and facilities had been upgraded based on learning from past experiences. A key example is the progress seen on LLW management and disposal in France in going from the Centre de la Manche below surface trench type disposal facility for LLW, to the more engineered monolithic above surface Centre de l'Aube LLW disposal facility (Tichauer 2010) (Figure 5.2).

The Centre de la Manche operated from 1969 to 1994 and ~500 000 m^3 of waste was disposed over a surface area of 12 hectares. A cap over the waste disposals was installed in the period 1991 to 1995 (Figure 5.3), and in 2003 following a period of initial monitoring, the facility was officially placed in a surveillance phase of active institutional control. Safety reports were prepared in 1975, 1982, 1988, 1994, 1998, 2004 and 2009.

The Centre de l'Aube has operated from 1992 and in total will receive ~1,000,000 m^3 of waste over a surface area of ~30 hectares. Safety reports have been prepared in, 1991, 1997 and 2004.

Improvements made when developing the Centre de l'Aube based on feedback and experience at the Centre de la Manche include (Tichauer 2010):

- The Centre de l'Aube was located at a site that provides more space, which has better hydrogeological characteristics and is further from the coast than the Centre de la Manche.

- The waste disposals at Centre de l'Aube are made above the water table.

- The disposal structures at Centre de l'Aube are designed to keep the wastes dry and include improved better arrangements for backfilling between waste drums.

- The disposal structures at Centre de l'Aube can be operated without the need for direct handling of the waste packages by workers.

- The disposal structures at Centre de l'Aube are structurally more stable and should, therefore, provide better support for the final cap.

- Waste package specifications and inventory limits at the Centre de l'Aube have been progressively improved using the safety case, and there are now precise records of waste package disposal locations and tighter limits on tritium and radium-containing wastes.

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Figure 5.2 Waste trench and manual disposal practices at the Centre de la Manche disposal facility (top) and improved facilities and disposal practices at the more modern Centre de l'Aube disposal facility (bottom) (Tichauer 2010).

- The Centre de l'Aube has simpler water collection systems, and uncontaminated rainwaters are kept separate from potentially contaminated waters.

- The final cap for the Centre de l'Aube will be designed taking account of lessons learnt from installing and monitoring the cap at Centre de la Manche. This suggests that the final cap at Centre de l'Aube should have a simpler design with shallower slopes.

In addition, the experience gained has allowed the improvement of regulations governing LLW disposal.

Such examples demonstrate the importance of learning from operational experience and updating the safety case to improve practices and thereby optimise the design and performance of the disposal facility.

5.5 INFLUENCE OF MONITORING ON FACILITY DESIGN

The desire to be able to monitor facility performance may have a direct influence on disposal facility design. Examples of this may be illustrated by considering the Centre de la Manche in France and the design proposed for short-lived L/ILW disposal at Dessel in Belgium.

At the Centre de la Manche in France, the operator, ANDRA, is required to:

- '*Monitor the behaviour of the disposal system.*

- *Have a monitoring system that will detect any abnormal situation or changes in order to locate the source, identify the causes and initiate corrective actions.*

- *Assess the radiological and chemical impacts of the facility on population and the environment, and to monitor such changes and impacts'.*

The facility cap was, therefore, specifically designed so that, in addition to promoting waste isolation by reducing the likelihood of intrusion by natural processes, humans, plants and animals, it would have a 'chevron style' form (Figure 5.3) that, in conjunction with four separate drainage networks, promotes effective monitoring and management of water run-off and seepage (e.g. Chino et al. 1999; Tichauer 2010).

Figure 5.3 1993 aerial view of the cap being constructed over the Centre de la Manche LLW disposal facility in France.

The preliminary facility design for disposal of short-lived L/ILW disposal at Dessel in Belgium is illustrated in Figure 5.4 (see ONDRAF/NIRAS 2007 and Van De Velde 2011).

The design specifically includes inspection galleries that will make it possible to monitor potential radioactive and toxic contamination in water that eventually penetrates down through the cover and the disposal modules. To place the inspection galleries above the water-table, which is very close to the ground surface in the region, whilst at the same time permitting drainage via the galleries by gravity, the disposal modules will be raised above ground-level. This is an example of tailoring facility design to the particular characteristics of a site – further such examples are given in Section 5.6.

Each disposal module has an inspection room beneath it, which is accessible via the inspection galleries. In an earlier design the inspection rooms were two metres high and were constructed on a 0.6 metre-high embankment. The inclusion of the inspection rooms in the design is a consequence of the importance attached to visual checks on the facility and, in particular, to monitoring for any unacceptable cracks in the disposal module slabs and the penetration of water bypassing the normal drainage systems. In the most recent design, the height of the inspection rooms has been reduced to between 60 to 80 cm so as to reduce the chance of human intrusion and enhance security. This will mean that examination of the rooms and the bases of the modules will have to be conducted using robots rather than by human inspection (Van De Velde 2011).

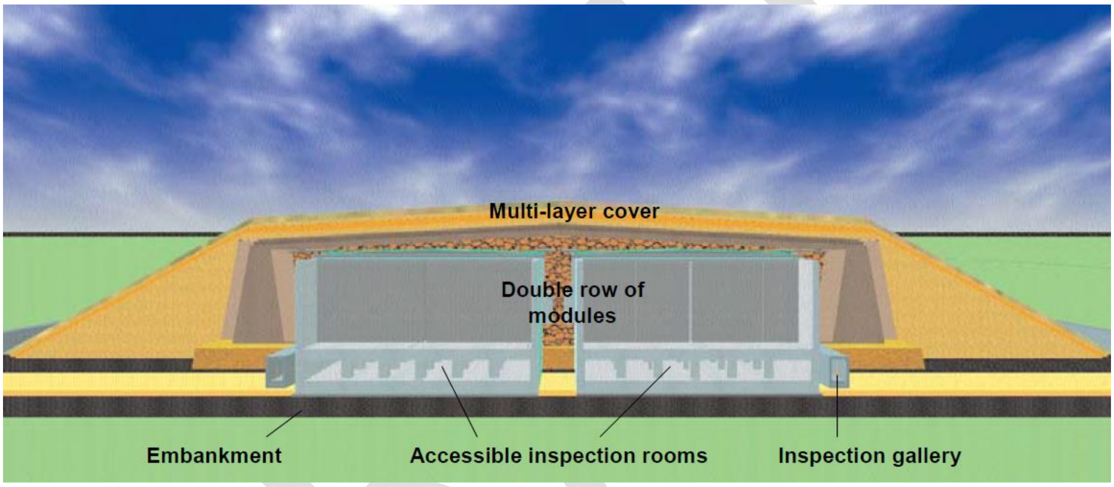

Figure 5.4 Preliminary design of a near-surface disposal facility for the disposal of short-lived L/ILW in Belgium. Note the inclusion of inspection rooms and galleries.

Another interesting feature of the latest design is the proposal to place a gravel layer between the module walls and the concrete waste containers (which are also known as monoliths) to provide stability in the event of earthquakes and improve waste retrievability (Van De Velde 2011).

Facility closure will be a progressive process. All the access paths to the emplaced waste will be blocked and the last engineered barriers, such as the multi-layer cover, will be constructed. It is possible that final covering of the facility may be deferred for a number of decades after completion of waste emplacement, for monitoring purposes. Closure will also include sealing of the drainage system and filling of the accessible inspection rooms and galleries. Keeping the inspection rooms and galleries open for a sufficiently long period following emplacement of the multi-layer cover would allow for verification of the facility and, thus, a demonstration of adequate system performance. This, however, would have to be balanced against the decision to bring the disposal facility in its final condition for passive safety (ONDRAF/NIRAS 2007).

These examples illustrate the potentially significant effect of monitoring requirements on disposal facility design. Monitoring arrangements can be a key issue for discussion with regulators and other stakeholders.

5.6 THE INFLUENCE OF SITE CHARACTERISTICS ON DISPOSAL FACILITY DESIGN

The characteristics of a site will influence the design of a radioactive waste disposal facility. Examples of technical factors that may need to be considered include proximity to population centres, site stability, topography, seismicity, earthquakes, volcanic activity, weather and climate, vegetation, climate change, flooding, proximity to rivers, lakes and the coast processes, erosion, the potential for water abstraction and mineral and oil and gas extraction, site hydrology and geochemistry, the ease of waste transport, potential radionuclide release and transport pathways, land ownership and possible future site uses.

The following paragraphs discuss two differing examples; the first from an arid site in Israel and a second from a site in Slovenia that has the potential for flooding.

The Israel national waste repository is located on the Yamin Plateau in NE Negev. This site was chosen after a detailed survey, mainly considering geological and meteorological aspects. The Yamin Plateau is a desert area with annual average of 70 mm of rain and potential evaporation of 2,600 mm/y. The geological structure of the site forms a syncline, where the upper formation is continental sediments of sand, sandstone, clay and conglomerate. Beneath this upper layer is a sequence of more than 200 m of marine sediments, including marl, clay and chalk, which serve as natural barriers to prevent the migration of radioactive waste to a deeper fossil saline aquifer located about 500 m below surface.

A study conducted in parallel with the site characterisation work evaluated distribution coefficients (K_ds) in the sand layer. This study involved laboratory experiments and showed very high K_d values, which means that strong absorption of radionuclides can be expected (Dody et al. 2006). The risk of aquifer contamination was, thus, found to be negligible, which implies that the near-surface waste disposal facility is more sensitive to surface processes such erosion.

A study to evaluate the erosion rate was conducted using several methods. The main method used the Optical Stimulation Luminescence (OSL) technique and this showed that over the last 14,000 years the erosion rate has been 0.3 mm/y (Dody et al. 2008). This conclusion led to a decision to upgrade the cap layers of the existing disposal sites and increase the depth of the cap design for new facilities.

The second example relates to the choice of facility design for the disposal of low- and intermediate-level radioactive wastes in Slovenia. After an extensive process to find a site for a new repository, which involved the Slovenian Government, various possible sites proposed by volunteer communes, and the Slovenian waste management organisation, ARAO, a potential site at Vrbina-Krško was selected (Viršek 2010). Three broad types of design concept were considered; an above-ground, surface concept, a near-surface silo-type design, and a deep geological facility design. A key characteristic of the site is that it is located within a large river floodplain. This influenced the choice of design concept and argued against the above-ground option. In 2009 an Environmental Impact Assessment, supported by a preliminary safety report and a feasibility assessment indicated that a near-surface silo-type design would be safe and feasible. Given this a silo-type design was selected and a mode detailed design was developed Figure 5.5.

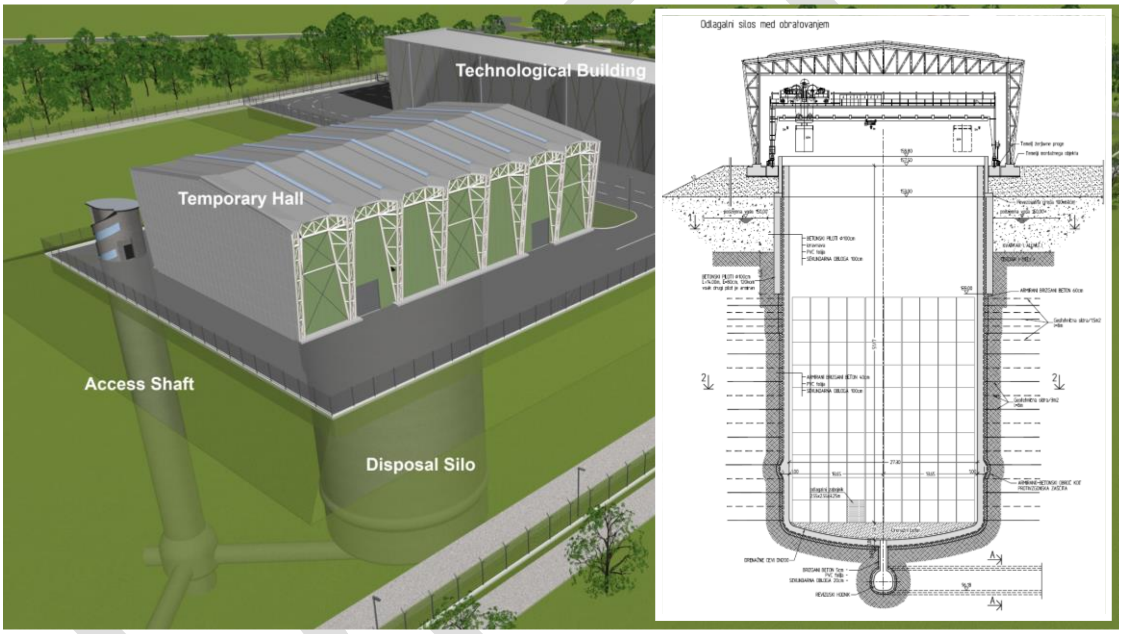

Figure 5.5 Illustration of the Slovenian concept and design for a disposal facility for low- and intermediate-level radioactive wastes (Viršek 2010).

5.7 INFLUENCE OF SAFETY ASSESSMENTS ON FACILITY DESIGN

This section discusses examples of the use of performance and safety assessment calculations to help arrive at decisions on disposal facility design. The first example discussed is based on a set of assessment calculations made for hypothetical disposal facilities by Rood et al. (2011). Similarities with other LLW disposal programmes are noted. A second example derives from a comparison made of ‘above grade’, ‘below grade’ and subsurface conceptual designs for the disposal of LLW at Dounreay in northern Scotland (UKAEA 2004).

Rood et al. (2011) undertook assessment calculations to evaluate the performance of several alternative designs for a hypothetical ‘below grade’ near-surface disposal facility for low-level wastes at a semi-arid site (Figure 5.6).

Hypothetical Disposal Facility System with Liner and Leachate Collection System

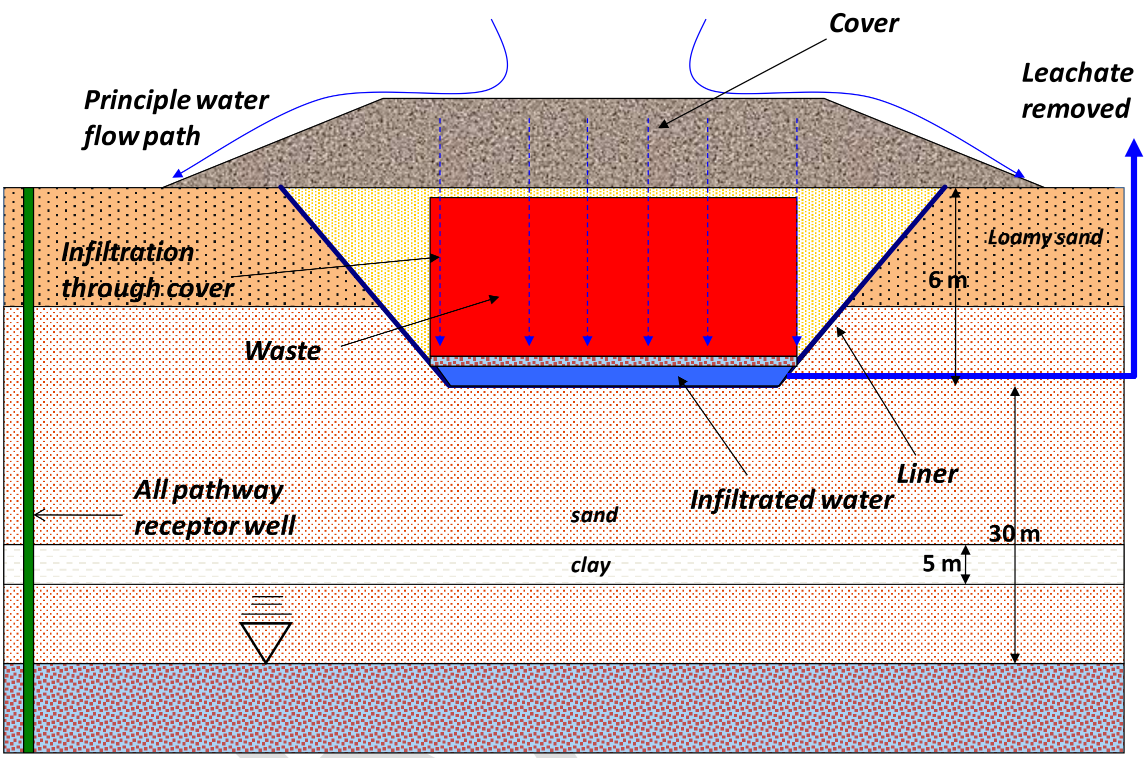

Figure 5.6 Hypothetical low-level waste disposal facility showing key design features, including a hydraulic isolation liner with a leachate collection system. Vadose zone lithology is also shown. (Rood et al. 2011).

Several different engineered barrier systems were evaluated in the following assessment cases:

- A disposal facility without a hydraulic isolation liner or additional waste containment. This provided a ‘base case’ against which the following alternatives were compared.

- A design alternative in which an anion exchange resin was assumed to be placed in the bottom of the disposal facility. This geochemical barrier would be designed to retard the movement of key anions such as iodine and technetium.

- A design alternative that included a conventional hydraulic isolation liner composed of a geosynthetic material, coupled with a leachate collection system that would remove water as it accumulates in the bottom of the facility. The hydraulic isolation liner was assumed to extend up to the top of the waste, and thereby eliminate any possibility of leachate escaping the leachate collection system during the 20-year operational period and the subsequent 100-year institutional control period. After institutional control, it was assumed that maintenance of the leachate collection system would stop and the facility would accumulate water. Two different cases were assessed for this design alternative – one in which the hydraulic isolation liner was assumed to fail at 500 years and release the accumulated water, and another in which the liner was assumed not to fail, leading to the facility filling with water and subsequently overflowing (‘bath-tubbing’).

- A design alternative in which the wastes were assumed to be contained in carbon steel containers separated by a sand infill material that would allow infiltrating water to pass through the facility between the steel containers. The design for this system would, thus, promote drainage of clean infiltrating water through the facility without contacting the waste. Again, two different cases were assessed for this design alternative – one in which the containers had a mean lifetime of 1,000 years and another with half the waste placed in a container having a mean lifetime of 500 years and the other half in containers having a mean lifetime of 1500 years.

In all cases the engineered cover was assumed to reduce infiltration by an order of magnitude from the natural infiltration rate (i.e., from 5.0 to 0.5 cm/year) and to remain intact for 500 years following closure of the facility. After 500 years, the cover was assumed to degrade such that the net infiltration increased linearly to 5 cm/year at 1,000 years after closure of the facility.

The waste form was assumed to be contaminated soil and miscellaneous waste in which the release mechanism would be surface wash with soil-water partitioning. The analysis considered radionuclides with a wide range of half-lives; H-3, C-14, Nb-94, Tc-99, I-129, U-238, U-234, Th-230, Ra-226 and Pb-210.

Doses were calculated for a receptor that drilled a water well 100-m down-gradient from the edge of the facility and set up a subsistence farm at that location. The receptor was assumed to be at this location for all times following facility closure. In the case involving bath-tubbing, because the hydraulic isolation liner was assumed to extend to near land-surface, contaminated radioactive leachate would be brought to the near-surface where it could contribute via an additional direct exposure pathway.

Key results from the assessment can be summarised as follows:

- All of the alternatives with additional engineered barriers performed better than the base case disposal facility without any hydraulic isolation or additional waste containment.

- During the 100-year institutional control period, doses for all cases depended on the ability to contain tritium. The hydraulic isolation and steel container alternatives provided the most effective means of containment during this period. The hydraulic isolation alternatives depended on maintenance of the leachate collection system throughout the 100-year institutional control period and it was assumed that the hydraulic isolation liner would remain intact through the first 500 years after installation. If the hydraulic isolation liner and or the engineered cover were to fail prematurely, and or leachate collection was to stop earlier, then the performance of the hydraulic isolation liner system would be adversely impacted.

- During the first 1,000 years after closure, doses for all cases were dominated by Tc-99. The cases involving use of steel containers and the geochemical barrier gave rise to the lowest doses. The case involving bath-tubbing led to the highest assessed doses.

- Doses after 1,000 years were reduced, as compared to the base case, through the use of the geochemical barrier and the steel containers. However, none of the alternatives significantly affected the transport of U-238, which was predicted to give rise to doses on the 100,000 year timescale.

In discussing the results of their assessment, Rood et al. (2011) highlight various other factors that would need to be considered when deciding on and implementing a particular facility design, including details of the extent of hydraulic liners, the choice of materials for containment and geochemical barriers, the characteristics of the site and costs.

Rood et al. (2011) note that it might be sensible to consider not extending the liners toward land surface, as keeping the sides low would limit the amount of water that could pond in the waste after the leachate collection system is turned off, prevent or limit saturated flow conditions from developing and reduce the potential for radionuclides to be released at land surface.

This suggestion is consistent with the aims of the Canadian IRUS conceptual design which was designed to minimise contact of water with the waste (by keeping the waste in a hydraulically unsaturated condition), ensuring long-term structural integrity, prevent human intrusion into the waste, restrict the loss of radionuclides from the vault and minimise the need for long-term maintenance (Dolinar et al. 1996; Jategaonkar 1999).

The Canadian IRUS design (Dolinar et al. 1996) is located at a site where the overburden is relatively permeable. The concrete walls and the roof of the vault are designed to exclude water from the facility. However, should these engineered barriers fail, a potential exposure pathway would become available via the infiltrating water. To reduce potential radiation exposures, the free-draining backfill that surrounds each waste package and the permeable vault bottom would prevent the accumulation of water in the vault. This design minimizes the contact time of water with the waste, and buffer layers in the floor are designed to sorb radionuclides leached from the waste.

The idea of keeping the waste in an unsaturated state is also at the root of the design proposed for future engineered vaults at the LLWR, which have low side walls to prevent bath-tubbing (LLW Repository Ltd 2011b).

USNRC (2000) gives guidance on performance assessment methods for LLW disposal facilities and emphasises the need for iteration between the assessments and facility design studies. It also emphasises the need to take an integrated approach and consider the disposal system as a whole, rather than as a series of individual barriers:

- *'An understanding of the nature of materials in engineered barriers, their make-up, and their interactions is needed in performance assessment, for estimating material longevity and for developing parametric values that represent the behavior of engineered barriers with time.*

- *Once the various materials that make up the engineered barriers and their spatial relationships are described, it will be necessary to evaluate how their integration into the composite system affects facility behavior.*

- *Factors that need to be considered in this process include: (a) compatibility among materials that may come in contact with each other, either directly or indirectly through material transport processes within the engineered barrier system; (b) the manner in which the disposal facility is to be constructed, including how construction joints, changes in geometry, penetrations, etc., may affect system behavior; (c) the effect that failure of a design feature or some portion of an engineered barrier would have on the overall behavior of the barrier; and (d) how the degradation of material properties affects barrier performance over time.*

- *The purpose of this integration step is to begin a logical design process, to ensure that all relevant materials and conditions that could affect the behavior of the waste disposal system, over the service life of the engineered barriers, are considered.'*

Assumptions made in performance and safety assessments regarding the rates of engineered barrier degradation may be particularly important. It is sometimes possible to simplify safety assessments by adopting pessimistic assumptions regarding the performance of engineered barriers (e.g. USNRC 2000). However, making overly-pessimistic assumptions in safety assessment can lead to the development of over-designed and unnecessarily costly disposal facility designs. Rather, facility design and design optimisation are better served by taking a realistic approach to the assessing the performance and longevity of engineered barriers based on the available knowledge and scientific data on the materials in question. For example, although USNRC (2000) takes a generally pessimistic view of the performance of engineered barriers in LLW disposal systems, it still makes the high-level recommendation that '*any period of time claimed for performance of engineered barrier*[s] *should be supported by suitable information and technical justification evaluated on a case-by-case basis.*'

The Dounreay nuclear licensed site on the coast of northern Scotland is being decommissioned. Work to date and future work at the site during the next two decades is expected to lead to the production of a significant volume (tens of thousands of cubic metres) of solid LLW (DSRL 2010).

In April 2004, UKAEA completed a study which concluded that the 'Best Practicable Environmental Option' (BPEO) for managing Dounreay's LLW is disposal in shallow below-surface facilities to be constructed at Dounreay.

Stage 1 of the Dounreay LLW long-term management strategy development project involved an objective review of LLW management options. This assessment of options was undertaken in the form of a BPEO study (UKAEA 2004) to provide. The use of BPEO analysis to support the decision-making process is consistent with UK best practice. The BPEO study was supported by around sixty individual technical assessments and reports. Three stakeholder workshops were held to review the options and identify the features and issues that were considered important by stakeholders. These workshops were followed by a three-month public consultation exercise.

To support the BPEO study, UKAEA undertook a performance assessment (the Run 1 PA) of the radiological performance of an above surface, shallow below-surface (10-m depth), and cavern (50-m depth) LLW disposal facility at Dounreay (Crawford and Galson 2002; Maul et al. 2002).

These performance assessment studies showed that all three facility types would meet radiological performance targets. Calculated radiological performance in relation to the groundwater pathway did improve with increasing depth of facility, but only improving from an already-compliant level (risks less than 10^{-6} per year). The main reason for improvement with depth was that once the near-field engineering degraded over the first hundreds or thousands of years after closure, releases from above-surface facilities were shown to have more potential to contaminate the soils between the facilities and the coast. Groundwater flows at depth are slower, and releases more likely to migrate to the marine environment offshore, rather than to land. However, because calculated doses are very low, the radiological impact from the groundwater pathway were not considered to be a strong distinguishing factor between alternative designs and depths for the disposal facilities.

According to Crawford and Galson (2002) both the probability and consequences of inadvertent intrusion and disruption decrease with depth of disposal:

- The probability decreases because the wastes are further from the human environment and surface-based activities and events. Facilities below the surface are less likely to be disrupted by natural events such as tsunamis or glaciation. Furthermore, a large artificial mound as would be created by the capping of above-surface facilities would be a prominent feature on the Dounreay coastal plain and could be seen as an obvious source of construction materials or be intruded through curiosity if awareness of the facilities had been lost in the far future.

- The consequences of inadvertent intrusion and disruption decrease with depth because intrusion of an above-surface facility is likely to involve direct disruption of more waste material, with greater associated risks, than for a below-surface facility. The trend is not linear, with a sharp decrease in risk until a certain depth is reached, coincident with the maximum depth likely to be reached by most construction-related activities (assumed to be the most likely future use of the area after knowledge of the facilities has been lost in the far future). Once below the depth of construction activities, there is little further reduction in the risk of intrusion with increasing depth until beyond the range of simple drilling activities, i.e., hundreds of metres.

During the Dounreay LLW BPEO study a wide range of factors was considered, not only the results of performance assessments (UKAEA 2004). The factors considered were:

Health and safety

1. Public health and safety
2. Worker health and safety

Environmental pollution

3. Physical environment
4. Flora and fauna

Technical issues

5. Viability
6. Flexibility
7. Scope for remedial action

Social, political and economic considerations

8. Local community
9. Need for future action

Cost

10. Cost

The result of considering these different factors for the range of potential waste management options was that a below-surface design was adopted for the New LLW Facilities, reflecting the benefits gained concerning radiological risks from human intrusion, visual impact, and material import compared to an above-surface design.

There may be marginal disadvantages concerning construction noise and management of drainage during operations, but these issues are considered insufficient to justify selection of an above-surface design. The current design favours location of the wastes a minimum of 4 m below current ground level, below the shallow weathered zone of potentially higher groundwater flows and at sufficient depth to be below the most likely intrusive activities. While a still deeper design may be marginally “safer” considering only post-closure disruption, there is not considered to be a further advantage to be gained in going deeper, as costs increase significantly and worker risks associated with construction and operation of the facilities may also increase (DSRL 2010).

Overall, the examples discussed in this section highlight the role that safety assessment can play in assisting with design choices, but it also clearly recognises the need to consider a wider range of both performance-related technical and non-technical factors when designing a disposal facility.

5.8 DESIGN DEVELOPMENT WITH CHANGING REGULATIONS AND REQUIREMENTS

As regulatory requirements develop and change, it might be necessary to revisit the design of the facility. The level to which this can be done particularly for licensed facilities that are already in operation depends, among other things, on the national regulatory context and nature of the facility.

In Sweden for instance, the regulatory bodies came to the conclusion that the regulatory requirements originally developed for geological disposal during the 1990's were also applicable to the existing SFR repository for short-lived low- and intermediate-level wastes (Wiebert and Efraimsson 2011). However, the requirements were only to be applied to the level possible. This implied that the operator needed to demonstrate fulfilment of the risk-based standard that was issued some ten years after the facility was taken into operation, whereas the operator did not need to demonstrate compliance with the requirements related to siting and intrinsic design features.

Another example from Sweden relates to the disposal of very low-level waste in shallow land burial facilities. Since the facilities were first licensed, the European Union has issued directives in respect of land burials of conventional hazardous and non-hazardous wastes that amongst other things place requirements on the performance of the cap and the geological barrier. These requirements would imply the need to revisit the design of existing shallow land burials for low-level radioactive wastes (SSI 2003).

5.9 TRIALS OF FACILITY CAP/COVER PERFORMANCE

The conduct large-scale tests and trials of the performance of caps and covers for near-surface disposal facilities is becoming increasingly common. Such trials are running or being planned in several countries, including Belgium, Spain, Slovakia and the US (e.g. at Hanford), and are typically planned to run for years to decades with the aim of providing better understanding of cap and cover performance and degradation, and providing valuable data for performance and safety assessment.

The design of the proposed Belgian LLW disposal facility at Dessel includes a multilayer cover. This cover consists of various different geo-materials, ranging from compacted clay to large sand boulders. On the basis of a step-wise approach, two designs have been developed: a reference design and an alternative profile

(Figure 5.7). Further refinements to the cover design and the final selection of the materials to be used will be determined based on cover performance tests.

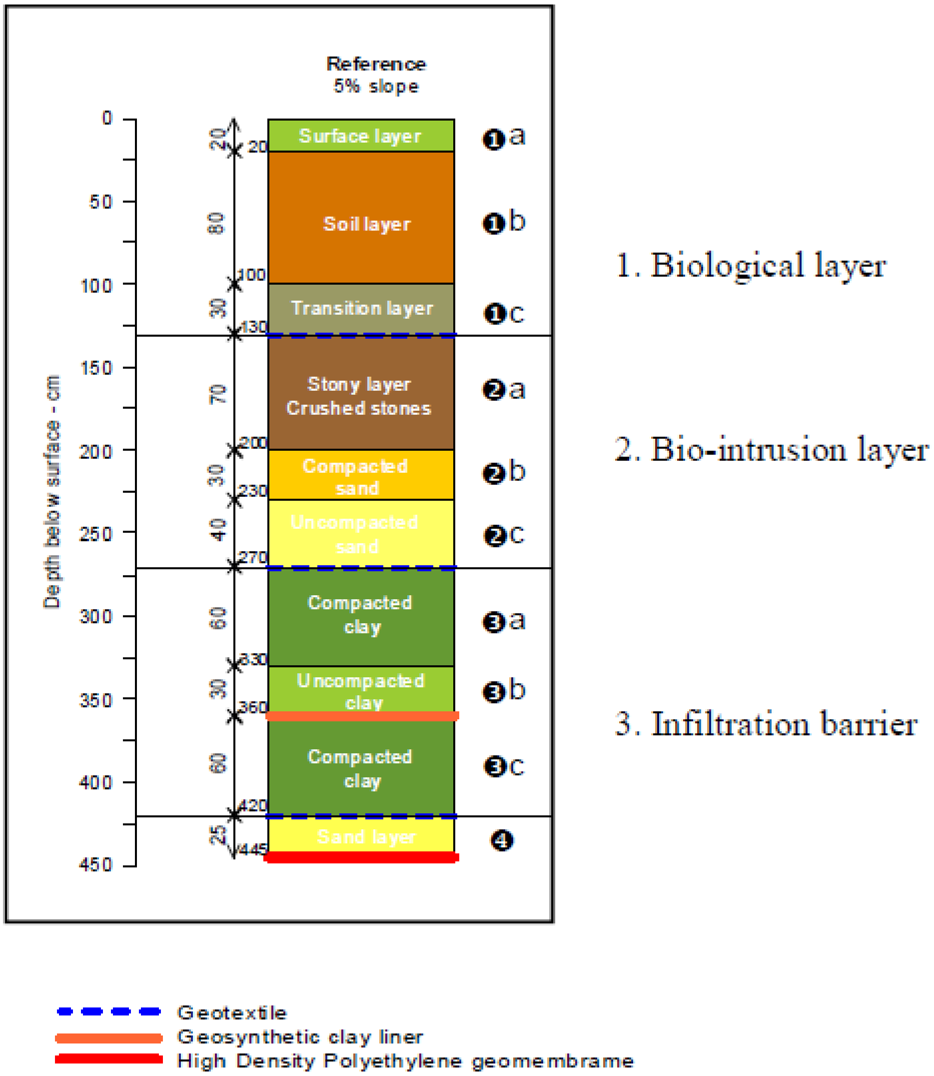

Figure 5.7 Preliminary cover design for a proposed LLW disposal facility in Belgium

Both the reference and alternative profiles consist of three layers:

- A biological layer, which is designed to ensure a stable growth of vegetation and allow infiltration of precipitation to limit erosion.

- A bio-intrusion barrier whose main objective is to protect the underlying layer from bioturbation due to plant growth and burrowing animals.

- An infiltration layer, which is designed to provide a barrier to further water percolation towards the underlying waste modules.

In Spain, Navarro et al. (2010) describe a large scale test of the long term engineered cap at the El Cabril LLW disposal facility. A key component of the El Cabril disposal system is the earthen cap that will provide long-term protection of the concrete LLW disposal vaults. The design of the cap is based on clay materials and two different designs have been considered. A large scale experimental set up has been built with three objectives: validating the two basic designs, verifying the thermo-hydraulic model of system performance, and supporting the enhancement of the safety assessment of the facility.

The test includes two test areas, one for each design variant. The test consists of constructing two adjacent multiple layer coverings, each measuring approximately 10 x 12 m, at the summit and 12 m in length down the slope, separated by a concrete gallery from which access may be gained to the instrumentation of the different layers. The base of the slope ends in a containment wall facilitating the removal of water from certain of the layers. A complete set of temperature, humidity, capillary pressure, and heat flow sensors has been installed in different zones of each layer of the cap disposal. Construction of the test covering layer began in late May 2007 and finished in November 2008. The test will be under operation for five years. Issues under investigation include cap permeability and durability, cap slopes, rainwater runoff, drainage and cap erosion, and bio-intrusion. Various chemicals are being used to trace flow and transport in the different layers of the cap (Navarro et al. 2010).

6 CONCLUSIONS

The PRISM Working Group on disposal facility design provided a valuable forum for the exchange of information and experiences amongst those involved in near-surface disposal of radioactive wastes. The working group discussed many disposal facilities and programmes, and identified and discussed a range of high-level safety case arguments relating to disposal facility design. The working group also considered a range of more detailed examples.

The experience of the PRISM working group on disposal facility design suggests that:

- In concept, similar processes of facility design apply to all types of disposal facilities.

- The safety case should be developed and used to ensure that the safety requirements are met.

- Public participation and input from other stakeholders are important for acceptance and can have a strong influence on disposal facility siting and design.

- There is no single best design for a near-surface disposal facility – the design solutions arrived at will differ according to the circumstances and requirements of the waste disposal system (including the wastes, the site, the surroundings and stakeholders).

- The disposal concept, the site and the detailed design for the facility should be mutually compatible.

- The design must be shown to be technically feasible.

- The safety case provides an essential management tool which should be used to manage facility operation and consider disposal facility safety, and facility upgrades and extensions.

- There is a need for on-going iteration between safety assessment and facility design, both during facility development and at later stages.

- Within a disposal programme, strategic design decisions and design choices will need to be made using the safety case. This is because it is not feasible or economic to continue to research many alternative design options in great detail, and because, particularly at operating facilities, there is a need to take decisions and continue waste disposal.

- Large-scale trials and tests of capping systems for near-surface disposal facilities can be important for improving confidence in performance and safety assessments and are being conducted in several countries.

- The level of detail in facility design information needs to reflect the stage that the particular disposal system or programme has reached. Early in facility development and implementation, facility design information would be expected to be at a conceptual level, while later on as implementation is approached more detailed designs will need to be developed. For construction and operation, these designs will need to be fully translated into detailed engineering terms in order that the facility can be built as intended.

- Designs for different repository components may not all be at the same stage of detail or refinement at any particular time. For example, it may be necessary to finalise the design of vault drainage earlier than the final design of the facility cap, which might not need to be installed for years or decades.

- The development and maintenance of knowledge and expertise in waste disposal, safety case development and safety assessment is key to establishing and implementing designs for disposal facilities that meet their requirements and are safe.

- Managing disposal facilities over decades is a complex task and emphasises the need for knowledge management, the maintenance of design records and for on-going review and re-evaluation of past practices and safety cases to identify possible needs for facility upgrading.

7 REFERENCES

Chino, P., Duret, F. and Voinis, S. (1999) *The Centre de la Manche Disposal Facility: Entering into the Institutional Control Period*, WM'99 Conference, February 28 – March 4, 1999.

Crawford M.B. and Galson D.A. (2002). *Results for the Run 1 Performance Assessment of LLW Disposal Facility Options at UKAEA*, Dounreay. UKAEA Reference GNGL(02)TR34 Draft March 2002.

Dody, A., Saphier, M., Weiner, D. and Berent, Z. (2006) *Uranium Migration in Sandy Soil: Controlled Experiments*. I.J. of Earth Sciences, Vol. 5, No. 2, DOI:10.1560/IJES.55.2.103.

Dody, A., Nahlieli, A., Auni, Y., Cohen, H. Weiner, D. and Porat, N. (2008) *Late Quaternary Deposition and Erosion Processes Along the Margins of the Yamin Plane, NE Negeu, Israel*, J. of Earth Sciences, Vol. 57, No. 3-4. DOI: 10.1560/IJES.57-3-4.199.

Dolinar, G.M., Rowat, J.H., Stephens, M.E., Lange, B.A., Killey, R.W.D., Rattan, D.S., Wilkinson, S.R., Walker, J.R., Jategaonkar, R.P., Stephenson, M., Lane, F.E., Wickware, S.L. and Philipose, K.E. (1996) *Preliminary Safety Analysis Report (PSAR) for the Intrusion Resistant Underground Structure (IRUS),* AECL-MISC-295 (Rev. 4), AECL, Chalk River, Ontario, Canada.

DSRL (2010) *Dounreay New Low Level Waste Facilities, RSA 93 Environmental Safety Case 2010.* Dounreay Site Restoration Limited Report No. NLLWF/3/ESC/GAL/0425/IS/01.

EC (1996) Council Directive 96/61/EC of 24 September 1996 Concerning Integrated Pollution Prevention and Control, Art. 2(11).

EC/NEA (2010) *The Joint EC/NEA Engineered Barrier System Project: Synthesis Report (EBSSYN)*, Bennett, D.G., European Commission Report No. EUR 24232.

Environment Agency, Northern Ireland Environment Agency and Scottish Environment Protection Agency (2009) *Near-Surface Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation*. February 2009.

Environment Agency (2010a) *Radioactive Substances Regulation (RSR) Environmental Principles (REPs)*, EA Regulatory Guidance Series, No RSR 1, Version 2, Bristol, UK.

Environment Agency (2010b) *Radioactive Substances Regulation (RSR): Principles of Optimisation in the Management and Disposal of Radioactive Waste*, Bristol, UK.

Haart, J. (2010) *Surface Storage Facility Design – the Netherlands*, Contribution to the IAEA PRISM Plenary Meeting, Vienna.

IAEA (2001a) *Performance of Engineered Barrier Materials in Near-Surface Disposal Facilities for Radioactive Waste,* Results of a Co-ordinated Research Project, IAEA-TECDOC-1255, International Atomic Energy Agency, Vienna.

IAEA (2001b) *Technical Considerations in the Design of Near-Surface Disposal Facilities for Radioactive Waste*, IAEA-TECDOC-1256, International Atomic Energy Agency, Vienna.

IAEA (2004) *ISAM - Improvement of Safety Assessment Methodologies for Near-surface Disposal Facilities, Volume I: Review and Enhancement of Safety Assessment Approaches and Tools*, International Atomic Energy Agency, Vienna.

IAEA (2005) *Upgrading of Near-surface Repositories for Radioactive Waste*, IAEA Technical Reports Series No.433, International Atomic Energy Agency, Vienna.

IAEA (2006) *ASAM - Application of Safety Assessment Methods to Near-surface Disposal Facilities for Low-Level Radioactive Wastes*, International Atomic Energy Agency, Vienna.

IAEA (2011) *Specific Safety Standards for Protecting People and the Environment: Disposal of Radioactive Waste*, IAEA Specific Safety Requirements No. SSR-5, International Atomic Energy Agency, Vienna.

IAEA (2012) *The Safety Case and Safety Assessment for the Disposal of Radioactive Waste,* IAEA Specific Safety Guide No. SSG-23, International Atomic Energy Agency, Vienna.

IAEA (in prep.) *Near-surface Disposal of Radioactive Waste, Draft Safety Guide DS356*, International Atomic Energy Agency, Vienna.

Jategaonkar, R.P. (1999) *Intrusion Resistant Underground Structure (IRUS) Facility for Disposal of Low-Level Radioactive Waste,* Transactions of the 15th International Conference on Structural Mechanics in Reactor Technology (SMIRT-15), 15-20 August 1999, Seoul, Korea.

LLW Repository Ltd (2011a) *The 2011 Environmental Safety Case: Environmental Safety Case - Main Report*, LLW Repository Limited Report No. LLWR/ESC/R(11)10016.

LLW Repository Ltd (2011b) *The 2011 Environmental Safety Case: Optimisation and Development Plan.* LLW Repository Limited Report No. LLWR/ESC/R(11)10025.

Maul P.R., Egan M.J., Penfold J.S.S. and Walke R.C. (2002). *Review and Analysis of the Run 1 Performance Assessment*. UKAEA Reference GNGL(02)TR40 Draft March 2002.

Motiejůnas, S. (2010) *New Capping System for a Radon-Type Disposal Facility*, Contribution to the IAEA PRISM project, Vienna.

Navarro, M., Zuloaga, P. and Ordoñez, M. (2010) *Large Scale Test of the Long Term Engineered Cap at El Cabril LLW Disposal Facility in Spain*, Waste Management 2010 Conference, March 7-11, 2010, Phoenix, Arizona, US.

NEA (2004) *International Project on Engineered Barrier Systems (EBS): Proceedings of EC-NEA Workshop "Design Requirements and Constraints" Turku, Finland, 26-29 August 2003*. OECD Nuclear Energy Agency.

NISDF (Nuclear Industry Safety Directors Forum) (2010) *Best Available Techniques (BAT) for the Management of the Generation and Disposal of Radioactive Wastes, A Nuclear Industry Code of Practice,* Issue 1.

ONDRAF/NIRAS (2007) *The Long-Term Safety of Disposal of Category A Waste: ONDRAF/NIRAS Safety Strategy and Safety Concept. Project Near-surface Disposal of Category A Waste at Dessel*, ONDRAF/NIRAS, NIROND-TR Report No. 2007-06 E, Version 1.

ONDRAF/NIRAS (2009) *The Long-Term Safety Strategy for the Geological Disposal of Radioactive Waste*, SFC1 Level 4 Report: Second Full Draft, ONDRAF/NIRAS, NIROND-TR Report No. NIROND-TR 2009-12 E.

Ormai, P. (2011) *Role of Safety Assessments in Supporting Decisions on Hungarian Near-Surface Repository*, Presentation to IAEA PRISM Plenary Meeting, 19-23 April 2010, Vienna.

Rood, A.S., Schafer, A.L. and Sondrup, A.J. (2011) *An Evaluation of Long-Term Performance of Liner Systems for Low-Level Waste Disposal Facilities*, Paper No. 11455, Waste Management 2011 Conference, February 27-March 3, 2011, Phoenix, Arizona, US.

SKB (2008) *Safety Analysis SFR 1, Long-Term Safety*, Swedish Nuclear Fuel and Waste Management Company Report No. R-08-130.

SKB (2011) Long-Term Safety for the Final Repository for Spent Nuclear Fuel at Forsmark: Main Report of the SR-Site project. SKB TR-11-01.

SSI (1998) *The Swedish Radiation Protection Institute's Regulations on the Protection of Human Health and the Environment in connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste*, SSI FS 1998:1, Stockholm, Sweden.

SSI (2003) *SSI's and SKI's Review of SKB's Updated Safety Analysis Report for SFR-1.* SSI Report 2003:21 (in Swedish).

SSI (2005) *The Swedish Radiation Protection Authority's Guidelines on the Application of the Regulations (SSI FS 1998:1) Concerning Protection of Human*

Health and the Environment in Connection with the Final Management of Spent Nuclear Fuel and Nuclear Waste, SSI FS 2005:5, Stockholm, Sweden.

Tichauer, M. (2010) *From CSM to CSA: 20 Years of Feedback. Regulatory Approach*, Presentation to IAEA PRISM Plenary Meeting, 19-23 April 2010, Vienna.

UKAEA (2004) *Dounreay LLW Strategy Development Best Practicable Environmental Option Study – Final Report*, UKAEA Report No. GNGL(04)TR75.

US NRC (2000) *A Performance Assessment Methodology for Low-level Radioactive Waste Disposal Facilities*, US Nuclear Regulatory Commission Report No. NUREG-1573.

Van De Velde, T. (2011) *PRISM Design Belgium*, Contribution to the IAEA PRISM Plenary Meeting, 31 October – 4 November 2011, Vienna.

Viršek, S. (2010) *LILW Repository in Slovenia – the Site and Disposal Concept,* Presentation to IAEA PRISM Plenary Meeting, 19-23 April 2010, Vienna.

Walker, J.R. (2011) *Port Hope Area Low-Level Radioactive Wastes – An Illustration of the Influence of the Public Participation on Facility Design*, Contribution to the IAEA PRISM project, 31 October – 4 November 2011, Vienna.

Wiebert, A. and Efraimsson, H. (2011) *Swedish Shallow Land Disposal Facilities for Radioactive Wastes from Nuclear Facilities*, Contribution to the IAEA PRISM project, Vienna.

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APPENDIX 2: PRESENTATIONS AND PAPERS

This Appendix provides a link to the presentations and papers received by the PRISM project Disposal Facility Design working group.

The presentations and papers may be accessed via the PRISM project website at:

http://www-ns.iaea.org/projects/prism/