European Partnership
on Radioactive Waste Management

3.2.2 LL-ILW containers; Domain Insight

EURAD Roadmap

1. National Programme Management
2. Pre-disposal
3. Engineered Barrier System
4. Geoscience
5. Disposal facility design and optimisation
6. Siting and Licensing
7. Safety Case

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The **EURAD Roadmap** is a representation of a generic radioactive waste management programme that shall enable users and programmes to access existing knowledge and active work or future plans in EURAD-2 and elsewhere. The content is focused on what knowledge, and competencies (including infrastructure) is considered most critical for implementation of RWM, aligned to the EURAD Vision.

All Roadmap documents can be accessed at the EURAD website: https://www.ejp-eurad.eu/roadmap.

The **Theme Overview Series** is part of the EURAD Roadmap, which is 7 high-level introductions to the EURAD Roadmap providing:

Guidance on typical goals and activities for RWM – Activities (which may be of variable importance and scope depending on the nature of the disposal programme) provide generic guidance on how to achieve key programme goals and how priorities evolve throughout programme phases, from advanced programmes perspectives.

Competencies for RWM – Needed competencies (and accessible infrastructure) for successfully managing a disposal program within the different phases of implementation.

The **Domain Insight Series** is part of the EURAD Roadmap, which in totality provides a high-level checklist of generic and typical activities needed for the full radioactive waste management lifecycle, leading to geological disposal including:

Functionality – Contextual information about how activities and knowledge associated with a domain contribute towards achieving generic safety and implementation goals.

Maturity and State-of-Knowledge (SoK) – Links to available SoK are included, providing an Experts' view of the most relevant knowledge and associated uncertainties (including areas of ongoing scientific and technological enquiry) in a specific domain applied in the context of a radioactive waste management programme.

Safety and Implementation Significance – Contextual information about how activities and knowledge associated with a domain impact long-term safety or practical implementation.

The **Domain Insight Series** of EURAD comprises over 70 short documents, prepared by Europe's leading Subject Matter Experts across Radioactive Waste Management. The documents are aimed at early career professionals or new starters interested in best practice and key knowledge sources.

Overview

Low and intermediate level waste (LL&ILW) represent the main part of the volume of radioactive waste which are produced by nuclear industry. This waste contains a large variety of materials such as paper, cardboard, plastics and metals with. The waste can also vary strongly in size and weight. Therefore, there is a need of various containers designs in order to condition the LL&ILW considering their physical and chemical properties. The main safety functions of a radioactive waste repository for Low Level and Intermediate Level Waste (LL-ILW) are the isolation, the containment and the shielding of the waste. Other safety functions can also be considered, such as the retardation of the radionuclide transport and maintaining stable conditions in the repository. The fulfillment of these safety functions relies amongst other on the Engineered Barrier System (EBS). During all the phases of the disposal programme, from its initiation to the closure of the disposal facility, safety assessments are performed and requirements are defined and updated in order to guarantee the safe management of the radioactive waste (during the operational and post-closure phases of the facility). The requirements for the design of LL-ILW containers are related to those for the disposal facility. The container requirements shall take into account the surrounding Systems Structures and Components (SSC's), as well as the external and internal potential perturbations (e.g. physico-chemical reactions) which could affect them. Depending on the concept of the repository and the defined safety functions and objectives, various materials such as concrete or steel can be used for manufacturing LL-ILW containers fulfilling the requirements. Such materials are currently used for the containers in various near surface LL-ILW disposal facilities currently in operation in countries such as France (CSA, Aube), the UK (LLWR, West Cumbria) and Spain (El Cabril, Cordoba). It shall be noted that LL-ILW can also be disposed in deep geological repository (e.g. Switzerland)

Keywords

Safety Concept, repository system, Engineered Barrier System, host rock, waste container, design requirements, radioactive waste

Key Acronyms

LL-ILW	Low Level and Intermediate Level Waste
EBS	Engineered Barrier System
SSC	Systems Structures and Components
DGR	Deep Geological Repository

1. Typical overall goals and activities in the domain of LL-ILW containers

The LL-ILW containers, as part of the Engineered Barrier System (EBS), shall contribute to guarantee the containment, isolation and shielding of the radioactive waste as long as necessary to reduce their radiological hazard. These safety functions must be ensured, both during the operational period and over the long-term (post-closure period from few hundreds to thousands of years). Whatever the chosen interim or disposal options (geological or near-surface), interactions with the barriers surrounding the containers as well as the retrieval options (if applicable) shall be investigated.

Requirements regarding the safety functions of the EBS are detailed in the following report: IAEA SSR-5 "Disposal of Radioactive Waste".

The table below provides the overall goal for the domain 3.2, extracted from the EURAD Roadmap goals breakdown structure (GBS). This is supplemented by typical activities, according to the phase of implementation, needed to achieve the domain goal. Activities are generic and are common to most disposal programmes.

Domain Goal	
3.2 Identify container materials and designs for each waste form under storage and disposal conditions and confirm properties, behaviour and evolution under storage and disposal conditions (Waste packages, for disposal).	
Domain Activities	
Phase 1: Programme Initiation	Based on the LL-ILW inventory to be disposed of, a set of basic requirements shall be established for ensuring that the safety objectives and requirements for disposal facilities set out in the regulatory framework are fulfilled. The safety requirements related to the containers will be derived from those of the disposal facility and from the waste inventory.
Phase 2: Site Identification	During this phase the site is identified and the basic requirements can be refined. RD&D projects can be carried out in order to identify the most suitable materials for the containers taking into account the potential interactions with waste on the one hand and the surrounding barriers on the other hand. Different concepts can be studied and compared for the disposal of the waste packages. The safety demonstration of each concept shall demonstrate that all the safety requirements will be performed during the operational phase and for the long term.

Phase 3: Site Characterisation	The containers shall be designed to guarantee the containment, isolation and shielding of the LL-ILW radioactive waste. The safety demonstration of the EBS (incl. containers) shall be made for the period where these safety functions must be fulfilled. This demonstration will rely, among other aspects, on the site characterization, providing the specific data (e.g. hydrogeological, chemical, etc) necessary to support the technical basis for safety assessments of the long-term containment and isolation of the waste within the disposal facility. Specific technical requirements (e.g. wall thickness) for LL-ILW containers shall be derived from these safety assessments. The design of the containers should take into account the types and quantity of waste that will be disposed of. A demonstration of the feasibility of the fabrication of waste packages should be carried out. The design of the containers should also take into account the operations such as the manutention (e.g. stacking), the controls (e.g. contamination) and monitoring that will be performed on the waste packages. The design shall finally take into account the possible retrievability options required by the regulatory framework, if needed.
Phase 4: Construction	The construction of the containers can be launched based on technical requirements and the approved design described in the safety case. These requirements shall guarantee the safety during the operational phase including incidental and accidental situation (e.g. drop of a waste package). The containers shall be manufactured in such a way to preserve the overall safety barriers. It shall be manufactured using well-mastered manufacturing techniques and following international standards (e.g. ISO or ASME standards). A quality management programme shall be implemented in order to guarantee the compliance of the manufactured waste containers with the applicable requirements.
Phase 5: Operation and Closure	Procedures shall be developed, based on design requirements, in order to guarantee the integrity of the containers during all the operations (conditioning, interim storage transport, loading in the disposal, controls, possible retrieval …). As the operational period could last a long time before the closure, a monitoring and an ageing program could be necessary. Procedures for overpacking must be developed in case that unacceptable damages (e.g. due to corrosion) are observed. The closure operations of the disposal facility shall be in compliance with the safety case and the license boundary conditions. During these operations, attention shall be paid to the waste packages in order to avoid unacceptable damages that could jeopardize the safety.

2. Contribution to generic safety functions and implementation goals

This section describes how LL-ILW containers and their associated information, data, and knowledge contribute to high level disposal system requirements using EURAD Roadmap Generic Safety and

Implementation Goals (see, Domain 7.1.1 Safety Requirements). It further illustrates, in a generic way, how such safety functions and implementation goals are fulfilled. It is recognised that the various national disposal programmes adopt different approaches to how disposal system requirements are specified and organised. Each programme must develop its own requirements, to suit national boundary conditions (national regulations, different waste inventories, different packaging concept options, different site environment, etc.). The generic safety functions and implementation goals developed by EURAD and used below are therefore a guide to programmes on the broad types of requirements that are considered, and are not specific or derived from one programme, or for one specific disposal concept.

2.1 Features, characteristics, or properties of LL-ILW disposal containers that contribute to achieving operational safety as well as long-term safety of the disposal system

Considering the waste packages, external and internal factors can influence the performance of the containers and compromise their safety functions.
Internal factors are related to the boundary conditions provided by the waste form inside the containers. These conditions can vary depending on the composition of the waste and, if applicable, the conditioning matrix. External factors are related to the chemical and physical boundary conditions provided by the surrounding barriers (air, concrete, backfill, etc) and the host rock (for geological repositories). Therefore, the materials composing the EBS structures and components should be compatible with each other, in order to prevent interactions leading to an early degradation of the performances of one or more components.

2.1.1 Primary goal – long-term safety

Regarding the long-term safety, LL-ILW containers, as part of the EBS, shall contribute to the isolation and the containment of the radioactive waste. Depending on their safety goals, they can also contribute to the retention and retardation of the radionuclides and to maintaining the stability of the waste disposal.

Isolation

In the case of DGR (Deep Geological Repository), this safety goal will be mainly accomplished by the geological barrier surrounding the waste disposal facility. For near surface disposal, isolation can rely on the containers being part of the EBS. In this case, the safety demonstration should address the isolation capacity of the containers.

Containment

Multiple barriers can be involved in this safety function, such as the waste form, the containers, the Engineered Barrier System and, for DGR, also the host rock. Depending on the extent in which the containers will be involved in this safety function, the safety demonstration could rely on these as well.

Retention and retardation

As also mentioned for the containment, this safety function can be achieved by multiple barriers forming the EBS and the host rock. If the container is part of barriers ensuring the retention and retardation, it should be designed accordingly. A safety demonstration should additionally be performed in order to demonstrate the compliance of the container with the safety goal

Internal stability

Depending on the disposal concept, the waste containers could contribute to maintaining the stability of the disposal facility. In this case, the waste containers shall comply with specific requirements, regarding their mechanical resistance, for instance. For example, in the Belgian concept for near surface disposal facility of LL-ILW (cAt disposal facility, Mol-Dessel), the waste containers will be stacked on five to six layers, making their mechanical resistance an important requirement.

As an illustration, the LL-ILW concrete containers for the Belgian near surface disposal facility shall meet the following requirements related to the long-term safety:

- Prevention from human intrusion;
- Chemical retention by containers components through which radionuclides can migrate;
- low effective diffusion;
- low effective hydraulic conductivity and no continuous cracks in the walls of the containers;
- resistant to internal and external sulphatic attacks;
- avoidance of alkali-aggregate reactions;
- resistance to freeze-thaw cycles;
- slow carbonation rate;
- low crack width (shrinkage);
- prevention from reinforcement corrosion;
- use of compatible materials.

2.1.2 Secondary goal – operational safety during the emplacement phase and retrieval (if applicable)

The disposal facility and its SSCs shall be designed in a way to guarantee the safe handling of the waste packages during the loading operations and an adequate protection from the possible hazards during operation (e.g. fire). In addition to the required safety functions listed above for the long-term safety, the LL-ILW containers shall therefore also provide sufficient shielding for the radiological protection during all processes of the operational phase (during normal operations as well as during accidental situations described in the safety case). The containers shall also be designed to allow the safe loading in the disposal facility and the controls of their condition in compliance with the control programme described in the safety case. If applicable, the safety demonstration shall demonstrate that the waste packages can be safely retrieved during a well-defined period (depending on the regulatory framework). Finally, procedures shall also be put in place to guarantee that the waste containers will not be damaged during the full process occurring throughout the operational phase.

2.2 Features, characteristics, or properties of LL-ILW containers that contribute to achieving interim storage safety and feasible implementation of disposal

2.2.1 Primary goals – containment and isolation

During the interim storage of the processed waste packages, it is essential that the waste containment and isolation is ensured in compliance with the safety case of the interim storage facility. These safety functions can be, in some cases, (partially) provided by the waste containers for interim storage. Usually, interim storage periods are calculated and licensed for 40 to 60 years with optional extension (if safety is demonstrated) until a disposal facility is available. Depending on the disposal concept, the containers used for interim storage can be also used as disposal containers. In some cases, an overpacking could be necessary in order to fulfil all the requirements described in the safety case of the disposal facility.

2.2.2 Secondary goal – shielding

Depending on the concept and the design of the interim storage facility, the waste containers can contribute to the shielding of the radioactive waste, allowing a limited dose rate in the interim storage facility (in accordance with the safety case of the interim storage facility). This shielding function can also be considered in the design of the disposal facility.

3. International examples of LL-ILW containers

The design of the LL-ILW containers can strongly vary depending on the disposal concept (geological or surface) and design.

In the Belgian near surface disposal (Mol-Dessel, Belgium) concept, the LL-ILW containers are made in reinforced concrete. There are three types of containers (I, II and III). The containers are filled with the waste and mortar in order to make monoliths. Depending on the container type, the monoliths can be stacked on five to six layers in the disposal facility. The LL-ILW concrete container is a square container with a wall thickness of 12 cm. The lid is also made of reinforced concrete and has a thickness of 8 cm (type I and II) or 12 cm (type III). The material used for the reinforcement of the containers is carbon steel. The container is equipped with four lifting anchors in the corners, allowing the handling of the monolith with the required accuracy. In the safety concept, the container (and its filling mortar) contributes to several safety functions (e.g. long-term containment and isolation of waste). It also contributes to the containment, shielding and isolation of waste during the operational period.

In the French CSA (Centre de stockage de l'Aube) surface disposal concept, the container, made of concrete or steel, contains the waste and its immobilisation matrix. The container is closed by a lid, or a layer of material (often cement-based) poured over the top. Different container designs are allowed in the CSA disposal facility: metallic drums (100, 200, 450 l), metallic containers (5 m³, 10 m³), cylindrical concrete shells (1 m³, 2 m³), fiber-reinforced concrete containers (5 m³), fiber-reinforced concrete shells (700 and 1,200 l). The container and its closing device contribute to the mechanical strength of the package and to the radiation shielding during handling of the waste packages. A metallic shielding may be added between the waste and the container, if necessary, to strengthen its shielding.

In the Spanish El Cabril (Cordoba) surface disposal facility for LL-ILW, the containers are made in concrete. The waste is first mainly immobilised in a 220-l drum which is placed in the concrete container and further immobilised with a mortar in order to form a compact block. The containers used in the El Cabril facility have a capacity for 18 packages of 200 L or 32 super-compacted pallets. The containers are designed to withstand extreme loads. The concrete recipe used in the containers was defined with the objective to optimise the durability of the concrete barrier.

4. Critical background information

The section highlights specific components, key information, processes, data or challenges that have a high impact or are considered most critical for implementing geological or surface disposal, with respect to the domain of LL-ILW containers.

4.1 Pre-disposal

Prior to the design of the LL-ILW containers, it is necessary to have a sufficient knowledge of the waste inventory and the conditions in the storage facilities. In some cases, an overpacking will be necessary before placing the waste package in the disposal container in order to guarantee sufficient shielding or to limit the risk of contamination. This risk can appear when, for instance, waste packages are degraded in case of extended interim storage due to delayed disposal options. The impact of the long-term behaviour of the waste form shall also be taken into account in order to anticipate future internal disturbances such as, for instance, a swelling of the waste due to a chemical reaction. Waste containers are subject to different sets of requirements during the different steps of their lifespan: manufacturing, waste loading, conditioning, storage, transport, and disposal. As the requirements may vary at each step, the performance criteria may also vary. The requirements and criteria should therefore be carefully mapped out and addressed at each step. The requirements should then be condensed to become design specifications.

4.2 Repository layout and design

A safety demonstration shall be performed in order to demonstrate this fulfilment in normal and in accidental conditions described in the safety case. A sufficient knowledge and understanding of the evolution of the disposal facility is necessary in order to estimate the various disturbances that the facility will have to cope with. The design of the containers will be based on specifications derived from the safety requirements described in the safety case on the one hand, and on the layout and the design of the repository on the other hand. The repository can be designed to allow different types of packages which will be disposed in dedicated disposal cells. The overall repository layout, the scope of waste handling facilities and disposal throughput can depend on both existing and projected waste volumes. The layout and design of the repository, together with its internal equipment, will take into account specifications related to both the design of the containers and the operations that will be performed during the operational period. This includes, where applicable, the retrieval operations of the waste packages after a well-defined period. These specifications can for instance be related to the dimensions and the mass of the containers, the handling features, the controls that will be performed, the decontamination operations, etc.

4.3 Post closure

An adequate understanding of the features of the disposal facility, its host environment and the factors that influence its safety after closure over suitably long time periods is necessary, so that a sufficient level of confidence in safety can be achieved. The safety assessment should not be limited to the evaluation of the performance and radiological impact of the disposal system, but should also contribute to develop an understanding of how the disposal system (the facility and its surrounding environment) may behave and evolve after its closure. The results of this assessment will be considered in the design of the containers and its improvement, if necessary. The design of the container shall also take into account possible monitoring to be performed during the post closure phase (e.g. probes for the radiological monitoring)

5. Maturity of knowledge and technology

This section provides an indication of the relative maturity of information, data and knowledge for disposal of LL-ILW containers. It includes the latest developments for the most promising advances, including innovations at lower levels of technical maturity where ongoing RD&D and industrialization activities continue.

5.1 Advancement of the safety case

Advancement related to the safety case depends on the advancement in the licensing process for a disposal facility. For LLW and short lived ILW (long lived ILW are mainly intended for DGR), the main disposal option retained is the near surface disposal. Such surface disposal facilities currently in operation are listed below (non-exhaustive list):

- UK – LLW Repository in Drigg, Cumbria operated by UK Nuclear Waste Management on behalf of the Nuclear Decommissioning Authority.
- Spain – El Cabril LLW and ILW disposal facility operated by ENRESA.
- France – Centre de l'Aube operated by Andra.
- Japan – LLW Disposal Center in Rokkasho-Mura operated by Japan Nuclear Fuel Limited.
- USA – five LLW disposal facilities: Texas Compact facility near the New Mexico border, operated by Waste Control Specialists; Barnwell, South Carolina operated by EnergySolutions; Clive, Utah (EnergySolutions); Oak Ridge, Tennessee (EnergySolutions); and Richland, Washington, operated by American Ecology Corporation.

In Belgium, the near surface disposal facility has been recently licensed for the first construction phase and the operation of the disposal is expected to start in 2029. Chapter 7 of the safety case of the Belgian near surface disposal facility describes the design requirements related to the waste concrete containers.

In the UK, containers specific requirements have been developed from those defined in the corresponding part of the Waste Package Specification (WPS/220/01), which provides the envelope to develop waste packaging proposals compatible with current illustrative concepts and the generic safety case for all aspects (transport to, operation, and the post-closure) of a DGR.

5.2 Optimisation challenges and innovations

An optimisation exercise can be performed on some of the design choices. During that exercise, the most optimal technical options for some well-defined SSCs can be selected. In doing so, alternative protection options can be weighed against attributes such as performance, durability, speed of completion of passive measures, layered protection, provability, and operational security. Based on these considerations, optimal design options can be finally selected.

Specifically for LL-ILW concrete containers, the following aspects could be addressed during optimisation:

- The type of reinforcement of the container.
- Whether or not to coat the outside of the container.
- Whether or not to galvanise the lifting anchors of the container.
- The detailed design of the lid of the container.
- The presence or absence of filler mortar between the waste and the bottom of the container.

5.3 Past and ongoing (RD&D) projects

The development of containers for LL-ILW has so far been considered internationally as a design activity of the WMOs or the waste producers in close correlation with the development of the repository design. Specific RD&D projects can be launched by WMOs in order to deal with specific issues like the corrosion of the reinforcement of concrete containers due to the presence of chlorine.

The DI 3.2.3 "Containers using advanced materials (Novel Containers)" describes the consideration of different materials for container production. EURAD work packages ConCorD (WP15) and PREDIS (WP7) also deal with waste containers. ConCorD is related to the optimisation and evaluation of the behaviour of materials for disposal containers in view of their long-term barrier performance. PREDIS dealt with the degradation processes and the monitoring of cementitious waste packages. Publications from these WP's can be found on the EURAD website.

5.4 Lessons learned

Each country, i.e., each responsible WMO, which has launched a programme to develop LL-ILW disposal containers, has its own experience of the complexity of the design process. In particular, some of the lessons learned are the need for validated data sets on the type, amount, and properties of expected LL-ILW over time, the expected interim storage time of individual waste containers, the type and characteristic of the host rock/geological environment of the proposed disposal, as well as on the decision/selection regarding the repository concept.

If a country/WMO has no design experience for LL-ILW containers, and the repository project is rather at an early stage, it may make sense to develop an approach that enables a systematic derivation of qualitative and quantitative requirements for the containers. Based on such an approach, a methodology to assess the transferability of existing national and international waste container concepts and for the development of generic container concepts that meet the requirements can also be developed. In this context, it should be noted that there is a limit to take advantage of already existing disposal container concepts, as there are usually many differences due to different regulatory frameworks, site (host rock) parameters, and potential repository concepts. The safety functions that must be covered by the containers can furthermore vary from a country to another.

6. Uncertainties

Uncertainties are present at all levels in the repository and shall notably be taken into account in the safety assessment and design of all the SSC' forming the EBS. The containers for LL-ILW are part of the EBS. In order to specify the detailed requirements for the containers, it is necessary that a decision on the repository concept and the appropriate EBS is made, and that the related uncertainties and their possible impact on safety are characterised and evaluated. As long as the site selection, repository concept and EBS have not been set, all concept and design activities and related uncertainties for disposal containers are of preliminary character.

In particular, the uncertainties on the waste chemical and radiological inventory shall be carefully assessed. Such uncertainties may have an important impact on the long-term evolution of the waste form, which can impact the performance of the container. An identification and assessment of the uncertainties having a potential impact on safety will allow defining safety margins in the design of the containers. It can for instance be decided, considering uncertainties on the lifetime of the containers and based on the assessment, to use a higher container wall thickness or to increase the reinforcement density for concrete containers.

7. Guidance

This section provides links to resources, organisations and networks that can help connect people with people, focussed on the domain of LL-ILW containers. Below the link to the UK Radioactive Waste Management (RWM) guidance for the design of low heat generating waste containers.

Guidance
WPS/890/01 - GD - Guidance on the Design of Waste Containers for Waste Packages Containing Low Heat Generating Waste

8. Further reading, external Links and references

8.1 Further Reading

- https://assets.publishing.service.gov.uk/media/5fb297df8fa8f55de86fb394/WPS_220_01_Part_C__Specification_for_Waste_Packages_Containing_Low_Heat_Generating_Waste.pdf
- https://assets.publishing.service.gov.uk/media/5e85ee87e90e0706ebaa8232/WPS_890_01_Guidance_on_the_design_of_waste_containers_for_waste_packages_containing_low_heat_generating_waste.pdf
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- https://www.researchgate.net/publication/332661539_Concrete_containers_in_radioactive_waste_management_a_review
- Gaggiano, R. and N. Diomidis (2023). 3.2.3 Containers using advanced materials (novel materials) - domain insight. HORIZON 2020 project EURAD. EC Grant agreement no: 847593
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- James BEGG, Marta LÓPEZ-GARCÍA, David GARCÍA (2023) , Domain 3.1.3 – Cemented LL-ILW, EURAD project, EC grant agreement N°847593

8.2 External Links

- https://www.datocms-assets.com/151156/1749630979-le-projet-cat-a-dessel.pdf
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- https://world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-waste/storage-and-disposal-of-radioactive-waste

8.3 References

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