




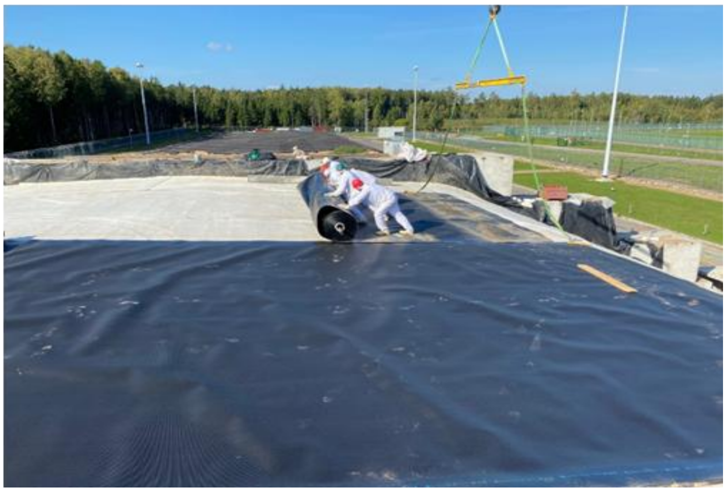

B19 Burial Campaigns

Lessons Learnt Report

KP-INPP-008

07/11/2025

Foreword

In 2021, the European Commission (EC) adopted a new proposal for a Council Regulation[1] establishing a dedicated financial programme for decommissioning nuclear facilities and managing radioactive waste. This instrument covers the co-funding of the decommissioning programmes of Bulgaria, Slovakia, and the decommissioning of the Joint Research Centre (JRC). A separate Council Regulation[2] was adopted for the decommissioning programme of Lithuania.

The EC JRC is mandated to foster the spread of decommissioning knowledge across all the European Union Member States and facilitate knowledge sharing arising from implementing the above-mentioned decommissioning programmes, funded by the Nuclear Decommissioning Assistance Programme (NDAP).

The decommissioning operators from the NDAP (NDAP Operators) implemented and tested a knowledge management methodology in 2021 through Project ENER/D2/2020-273. Using this methodology, the NDAP Operators can develop Knowledge Products that are currently available to share with other European stakeholders. In addition, this methodology is being implemented by the JRC Nuclear Decommissioning and Waste Management Directorate (NDWMD), which has become a knowledge generator extracting the knowledge from the ongoing decommissioning activities across the JRC´s four different sites (Geel, Ispra, Karlsruhe and Petten.

The JRC´s NDWMD aims to become a Centre of Excellence in nuclear decommissioning knowledge management and to develop a decommissioning knowledge platform which allows exchanging information building on EU best practices through executing the multi-annual financial framework (2021 – 2027) strategy. The operational phase of the project started in 2024 with the objectives to: develop ties and exchanges among EU stakeholders, document explicit knowledge and make it available through multi-lateral knowledge transfers on decommissioning and waste management governance issues, managerial best practices, technological challenges, and decommissioning processes at both operational and organisational level, as well as to develop potential EU synergies.

This is a Knowledge Product prepared by Nuclear Decommissioning and Waste Management Directorate (NDWMD) – Directorate J of the Joint Research Centre.

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[1] Council Regulation (Euratom) 2021/100 of 25 January 2021 establishing a dedicated financial program for the decommissioning of nuclear facilities and the management of radioactive waste, and repealing Regulation (Euratom) No 1368/2013

[2] Council Regulation (EU) 2021/101 of 25 January 2021 establishing the nuclear decommissioning assistance programme of the Ignalina NPP in Lithuania and repealing Regulation (EU) No 1369/2013

PRODUCT DESCRIPTION

This Knowledge Product (KP) describes Ignalina Nuclear Power Plant´s (INPP´s) lessons learnt from implementing a series of burial campaign projects, which constituted the: construction and commissioning of a landfill type disposal facility for short-lived very low-level combustible and non-combustible class A waste (i.e. VLLW) generated during the operation, decontamination and dismantling activities of the controlled area equipment. This document focuses on the difficulties and risks encountered during the first disposal campaign further complemented by additional information sourced from more recent campaigns.

ABSTRACT

This KP consolidates INPP's practical experience from the first three VLLW burial campaigns at facility B19 and provides a reusable playbook for future campaigns. It captures the engineered barrier configuration, waste acceptance criteria (WAC), organisation and resourcing choices, quality and safety controls, measured results, and key performance indicators (KPIs). Particular attention is paid to resolving procurement and specification gaps, as well as to the decision to perform the work in-house rather than outsourcing it. The document includes lessons learnt and recommendations in a "situation → decision → effect → recommendation" format, a KPI set with data collection methods, and anchors to the preliminary safety analysis report (PSAR) / operating basis for traceability.

OBJECTIVE

To record, convey and explain the knowledge gained during the construction and commissioning of a landfill-type disposal facility for short-lived very low-level waste (VLLW), by describing the difficulties and risks encountered, as well as the lessons learnt, across three burial campaigns (B19-1, 2 & 3).

APPROACH

This KP was developed using knowledge inputs provided by INPP. Those inputs referenced the updated safety basis, design documentation, methodological guidance, geological and hydrogeological investigations, radiological investigations and modelling, the quality assurance programme, as well as engineering and environmental measurements.

This KP covers: **(i)** an overview of the project and the objectives of the first disposal campaign; **(ii)** challenges and difficulties encountered during construction, commissioning and operation of the repository; **(iii)** safety measures, monitoring arrangements and regulatory aspects; **(iv)** KPIs) and **(v)** lessons learnt and recommendations for future campaigns.

Acceptance criteria and limits (embedded summary)

The WAC referred to in this KP includes: (a) radionuclide-specific sum-rules for operational, evolution (leaching) and inadvertent intrusion scenarios; (b) package-level dose-rate and surface-contamination limits; and (c) limits on long-lived alpha activity (LLAA). The X/Y/Z sum-rules are defined over the same package radionuclide vector and must each be ≤ 1 (formulas below). Operational radiological limits at package level are: dose rate at 10 cm < **0.2 mSv·h⁻¹**; surface contamination **< 4 Bq·cm⁻² (β/γ)** and **< 0.4 Bq·cm⁻² (α)**. Long-lived α activity per package **≤ 4 000 Bq·g⁻¹**, with an average across packages **≤ 400 Bq·g⁻¹**. **Closed sealed sources** are **not** acceptable for disposal.

WAC and X/Y/Z method (self-contained)

Definitions

Let Q_i be the specific activity of radionuclide **i** in a package ($Bq \cdot kg^{-1}$).
Let $A_{i,1}$, $B_{i,1}$, $C_{i,1}$ be the limiting specific activities for radionuclide *i* ($Bq \cdot kg^{-1}$) derived, respectively, from:

- **evolution / leaching scenarios** (long-term post-closure behaviour) → limits $A_{i,1}$,
- **operational scenarios** (handling / operation) → limits $B_{i,1}$,
- **inadvertent intrusion scenarios** (e.g., human intrusion) → limits $C_{i,1}$.

Sum-rules (checked independently by scenario group)

$Y = \Sigma(Q_i / A_{i,1}) \leq 1$ (evolution/leaching)
$Z = \Sigma(Q_i / B_{i,1}) \leq 1$ (operational)
$X = \Sigma(Q_i / C_{i,1}) \leq 1$ (inadvertent intrusion)

These three groups represent mutually exclusive bases for compliance (they are not simultaneous). Therefore, each sum-rule is verified separately for the same package inventory $\{Q_i\}$.

Module-average flexibility (Y-flex)

A package with $1 < Y \leq 10$ may still be acceptable provided that the **module-average Y** over all packages remains < 1. This provision does **not** apply to X or Z.

How limiting activities are obtained (method)

For each scenario and radionuclide, the limiting **specific activity** is determined from dose-constraint division, e.g.:

- for concentration-based limits: $Conc_i = (Dose\_lim / Dose_{iu}) \times C_{iu}$,
  where **Dose_lim** is the applicable dose limit ($mSv \cdot y^{-1}$), $Dose_{iu}$ is the modelled dose from unit concentration, and C_{iu} is the unit concentration used in the model;
- analogous expressions are used for **total-activity** limits when the entire inventory participates.

This procedure yields the scenario-wise $A_{i,1}$ / $B_{i,1}$ / $C_{i,1}$ used in the X/Y/Z sum-rules.

Package-level operational limits (must be met in all cases)

- Dose rate at 10 cm from the package surface **< 0.2 $mSv \cdot h^{-1}$**.
- Surface contamination **< 4 $Bq \cdot cm^{-2}$** (**β/γ**) and **< 0.4 $Bq \cdot cm^{-2}$** (**α**).
- LLAA: ≤ **4 000 $Bq \cdot g^{-1}$ per package** and ≤ **400 $Bq \cdot g^{-1}$** on average across packages.
- **Sealed sources**: **not acceptable** for disposal.

Practical note

For many **short-lived** radionuclides, operational controls (Z) are often most restrictive; for **long-lived nuclides**, post-closure evolution (Y) or intrusion (X) typically governs acceptance.

Operational limits — quick reference

Parameter	Limit	Applies to	Purpose
Dose rate at 10 cm	$< 0.2\ mSv\cdot h^{-1}$	Each package	Worker protection
Surface contamination (β/γ)	$< 4\ Bq\cdot cm^{-2}$	Package surface	Clean handling
Surface contamination (α)	$< 0.4\ Bq\cdot cm^{-2}$	Package surface	Clean handling
Long-lived α per package (LLA)	$\leq 4\ 000\ Bq\cdot g^{-1}$	Package content	Long-term safety
Long-lived α average (LLA avg.)	$\leq 400\ Bq\cdot g^{-1}$	Average (module)	Long-term safety
Sealed sources	Not acceptable	All packages	Inventory control

Where this is used in the KP

- **Section 2.6** (**safety**): acceptance checks use the X/Y/Z sum-rules and the operational limits above.
- **Section 2.7** (**KPIs**): the "Waste Acceptance Compliance" KPI is based on first-pass conformity to X/Y/Z and operational limits; "Monitoring & Response Efficiency" and "Personnel Dose Control" provide corroborating operational evidence.

RESULTS, FINDINGS AND INSIGHTS

Three burial campaigns have been completed to date. In total, 3,557 packages were emplaced (RAP-N 462; RAP-S 2,410; RAP-J 66; RAP-B 619), corresponding to 11,656 m³ of waste or approximately 19.4% of the module capacity. Furthermore, an industrial operation permit for B19-2 was issued on the 30th of June 2025.

Project achievements (campaigns 1 – 3)

- Three disposal modules with multi-layer engineered barriers were constructed and commissioned.
- Radiation monitoring, fire protection and power supply systems were tested and confirmed functional.
- Safety performance was demonstrated under multiple scenarios, including normal evolution, degradation, accident conditions and intrusion scenarios.

Operational issues and corrective actions

- Subcontractor coordination issues were identified and addressed through tighter quality control and closer oversight.
- Waste package and container requirements were refined and aligned with International Atomic Energy Agency Specific Safety Requirements-6 (IAEA SSR-6) and ISO 1496-1 to ensure conformity with international transport and container standards.
- Pre-acceptance checks were moved into a buffer area (B19-1) and materials were staged on prepared pads near the module, which reduced crane idle time and on-module congestion.

RAP package codes — quick reference

Code	Plain meaning	Typical waste / content	Typical container / form	Notes
RAP-N	Non-compacted package	Bulky solid VLLW/LLW	Standard containers (incl. half-height ISO), not compacted	Sheets with WAC X/Y/Z + α, dose/contam limits, per the X/Y/Z method (see above "WAC and X/Y/Z method"
RAP-S	Compacted package	Compacted solids (bales / blocks)	Bales / blocks in approved outer packaging	Volume efficiency; first-pass QA is critical
RAP-J	Ion-exchange resins	Spent resins (pre-treated)	Drums / liners or approved containers	Moisture / conditioning controls apply
RAP-B	Crushed concrete / rubble	Inert mineral fractions	Big-bags / containers as specified	Granulometry / cleanliness per spec / WAC

Findings

- Specification harmonisation with actual market availability (e.g. drainage gravel fraction range, High-Density Polyethylene (HDPE) texture and elongation requirements, topsoil characteristics) reduced QA rejections and delivery delays.
- Standardised layer QA (one-page checklists, photo logs, weekly audits) reduced rework and made quality evidence-based and fully auditable.
- Logistics changes (buffer pre-checks at B19-1 and pre-staged material pads) reduced crane idle time and improved on-module flow.

Insights

- Keep the KPI set lightweight in the body of the report, BUT enforce strict data capture during the campaign.
- Pre-book rental equipment and manage shared use of cranes / forklifts using a resource calendar to avoid peak bottlenecks.
  Maintain a regulator milestone tracker with explicit buffers for submissions and approvals to support on-time licensing.

KPIs highlights

- CPI = 1.31 and SPI = 1.00, indicating delivery under budget and on schedule.
- Monitoring completion and response time, as well as first-pass WAC acceptance (per the X/Y/Z method explained above), are now tracked as recurring KPIs to demonstrate operational control and regulatory readiness.

TARGET USERS

This KP is a valuable contribution to entities involved in similar burial campaign projects such as decommissioning operators, contractors, waste management organisations and technologists among other entities with a vested interest in such projects. It is written for Project Managers and VLLW (Decommissioning) Engineers and is intended for direct application in planning and executing subsequent B19 campaigns as well as campaigns for analogous facilities.

APPLICATION, VALUE AND USE

The information contained herein provides practical guidance and recommendations for improving planning, procurement and communication during the design, construction and operation of radioactive waste repositories. It also emphasises the importance of careful planning, risk assessment and contingency measures for the success of such projects.

KEYWORDS

Decommissioning, very low-level waste, waste management, burials, commissioning, construction

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ACRONYMS

ALARA	As Low As Reasonably Achievable
CPI	Cost Performance Index
DKM	Decommissioning Knowledge Management
EVM	Earned Value Management
GCL	Geosynthetic Clay Liner
HDPE	High-Density Polyethylene liner
IAEA	International Atomic Energy Agency
INPP	Ignalina Nuclear Power Plant
ISFSF	Interim Spent Fuel Storage Facility
ISO	International Organisation for Standardisation
KM	Knowledge Management
KP	Knowledge Product
KPI	Key Performance Indicator
LLAA	Long-Lived Alpha Activity
NDAP	Nuclear Decommissioning Assistance Programme
NDWM	Nuclear Decommissioning and Waste Management
PSAR	Preliminary Safety Analysis Report
RAC	Risks and areas of concern
RAP-N/S/J/B	Non-compacted / Compacted / Ion-exchange resins / Crushed concrete packages
SAA	Safety Analysis / Assessment Agreement (site-specific)
SSR	Specific Safety Requirements
SWT&SF	Solid Waste Treatment and Storage Facility
SPI	Schedule Performance Index
VATESI	State Nuclear Power Safety Inspectorate
VLLW	Very Low-Level Waste
WAC	Waste Acceptance Criteria

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1. INTRODUCTION

1.1. Background and context

The **Nuclear Decommissioning and Waste Management Directorate** (**NDWMD**) of the **JRC** is running the Nuclear Decommissioning and Waste Management (NDWM) Programme for the nuclear sites of the European Commission (EC), with the majority of the activities currently focused on dormant facilities situated on the Ispra site (located in northern Italy).

In 2020 the Council of the EU issued **Council Regulations 100** and **101** in which they provided co-funding to the decommissioning programmes in three EU Member States (Slovakia, Bulgaria and Lithuania), this initiative is now commonly known as the **Nuclear Decommissioning Assistance Programme** (**NDAP**), as well as full funding to the internal NDWM Programme of the EC, run by the JRC.

The same regulations also mandated the JRC to initiate a project on knowledge management in NDWM, which is commonly referred to as the **NDKM Initiative**, based on the experiences and lessons learnt running the JRC and NDAP. The primary products of the NDKM Initiative, referred to as KPs, will be disseminated to European stakeholders in order to support new operators entering NDWM activities, enabling them to profit from knowledge generated by previous experience and programmes.

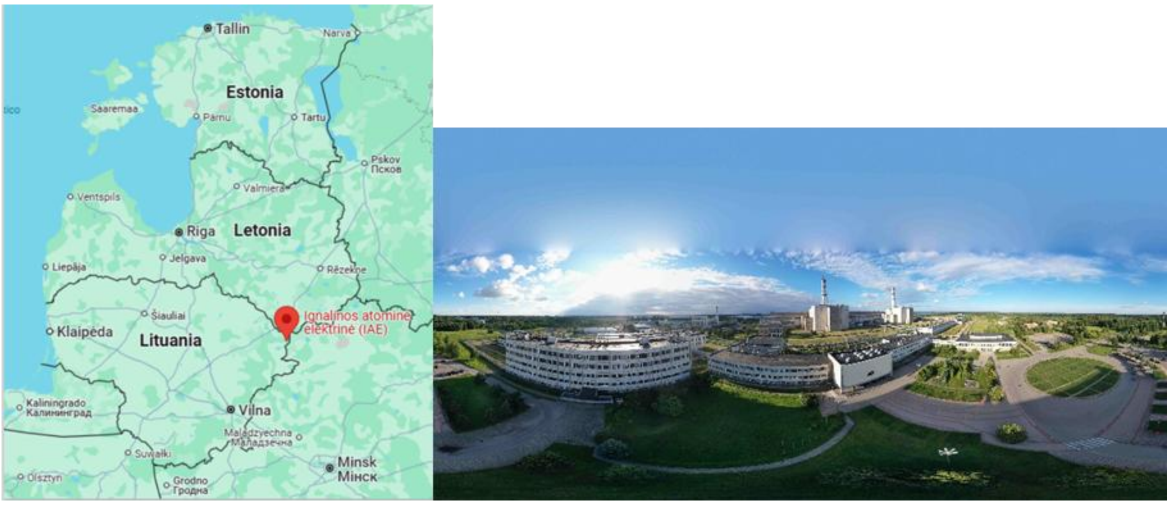

Figure 1. Snapshot of INPP's location on a map and panoramic view of the site

This KP builds on the progress made by the NDWM Programme in the past years by delving deeper into a lesser explored topic of a VLLW disposal facility burial campaign. The following paragraph provides context and elucidates the project´s strategic orientation, justification and relevance. Understanding the background reinforces why the project was necessary and what tasks it addressed.

1.1.1. Historical and technical context

- The operation and termination of operation of **RBMK reactors led to** the generation of **significant volumes of VLLW** which had accumulated and needed to be processed, including:
    - **combustible operational waste**: ~4,206 m³,
    - **non-combustible waste**: ~12,300 m³,
    - **decommissioning waste**: ~31,408 m³,
    - **total**: ~47,914 m³.
- **Lithuania´s international obligations** on safe management of radioactive waste.

The VLLW repository project was initiated within the framework of INPP´s decommissioning programme. During the dismantling of equipment and decontamination of premises, short-lived very low-level waste (VLLW-SL) was generated, for which no infrastructure existed for safe long-term disposal. The absence of infrastructure posed the challenge of developing a safe long-term disposal solution compliant with VATESI and INPP requirements, as well as in compliance with other international obligations and environmental protection requirements of the decommissioning strategy.

Table 1. Highlights (at a glance)

Topic	Highlight	Why it matters	Evidence
Regulatory	Industrial operation permit received on the 30th of June 2025	Confirms readiness for industrial operation	Completion report / Regulator letter
Throughput & capacity	3,557 packages / 11,656 m³ (≈ 19.4% of module capacity)	Shows progress vs design capacity	Campaign logs / Results
Cost & schedule (EVM)	CPI 1.31, SPI 1.00	Cost efficiency and schedule adherence	Project controls
Execution practice	Specification harmonisation (e.g., drainage 4 – 16 mm, HDPE role)	Fewer QA rejections and fewer delays	Change - control records

Table 2. Top risks and areas of concern (RAC)

Risk	Cause / context	Current controls	Residual risk
Specification vs market mismatch	Market supply ≠ initial specs (fractions, HDPE, topsoil)	Early market scan, spec harmonisation, change - control	Amber
Infiltration / cover erosion	Heavy rain, runoff, slopes	GCL + HDPE, drainage, mesh, vegetation, monitoring	Green
Resource bottlenecks	Crane / forklift peaks	Mixed INPP fleet + targeted rentals, resource calendar	Amber
Regulator cycles	Review / approval timing	Milestone tracker, prioritised submissions	Green

1.2. Overview of the project

> The project included the construction of three disposal modules, each of 20,000 m³ capacity, intended for the emplacement of VLLW. The modules were equipped with multi-layer engineered barriers, monitoring systems, buffer storage and infrastructure for control and operation.

The following list, as shown in Figure 2, details the **layout of the disposal modules and other on-site facilities**:

1. **disposal modules** of the landfill facility,
2. **fence** of the disposal module area,
3. **sites of complexes B1**, including the new Interim Spent Fuel Storage Facility (**ISFSF**), and **B3/4** the new Solid Waste Treatment and Storage Facility (**SWT&SF**),
4. **ramps** for vehicle inspection,
5. **control** (security) **building**,
6. **facility for collection of domestic wastewater**,
7. **underground tanks for collection of rainwater**,
8. **welfare/auxiliary premises** (to be periodically relocated in the direction of landfill filling),
9. **fuelling** point for vehicles.

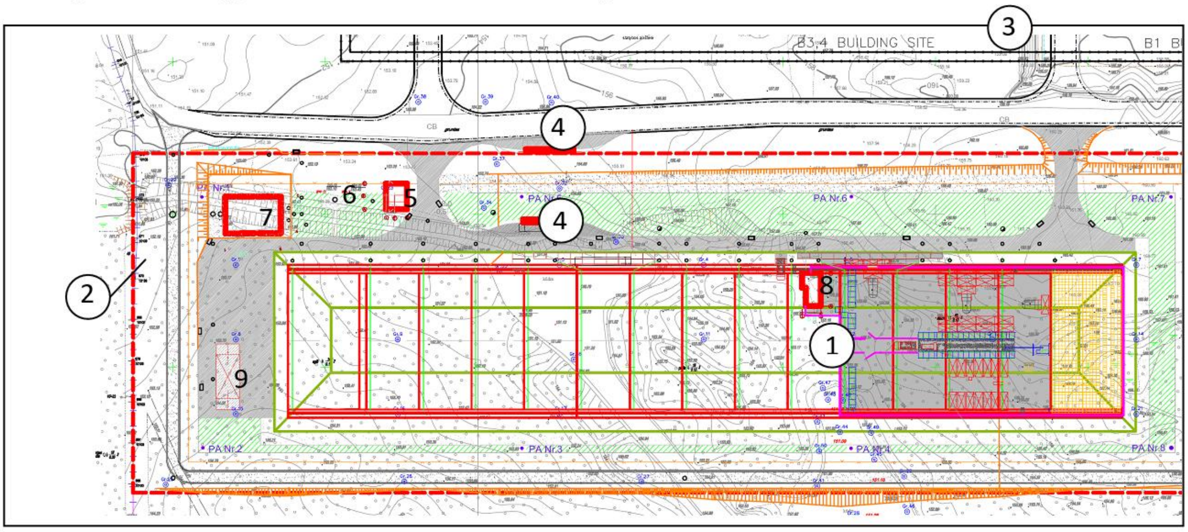

Figure 2. Layout of the disposal modules and other on-site facilities

Figure 3. Snapshot of works in progress

1.2.1. Hydrogeology brief summary

Hydrogeology was a very important consideration during the works, a summary of its main factors can be seen below:

Platform: gently sloped, designed runoff toward engineered collection drains.

Groundwater: monitoring wells at ~[depth] m below grade around modules (IDs: W-xx); baseline established pre-operation and trended across campaigns.

Drainage concept: cap slopes [x%], drainage layer conveys water to collection points; slab runoff routed to controlled sumps.

Erosion control: protective soil with vegetation; periodic inspection and re-seeding if needed.

1.3. Objectives, schedule and key stages of the burial campaigns

The burial campaigns had to satisfy the following **overarching objectives**:

- **provision of safe**, **controlled** and **licensed disposal** of VLLW,
- **minimisation of radiological impact** on personnel, the public and the environment,
- **compliance with VATESI** and **national legislative requirements**, and **alignment with IAEA safety guidance**.

1.3.1. Main activities

The projects were **complex infrastructure projects which comprised of multiple interrelated activities**, each of which contributed to the process of achieving the overall goals. All activities were integrated into a single logical sequence which ensured project goals were achieved and that sustainability was maintained throughout the facility´s life cycle.

A description of each main activity, accompanied by an objective, specific scope of activity and its contribution to the overarching objectives can be seen below:

Activity A: Design

Objective: development of a safe, robust and regulatory-compliant design.

Scope: geotechnical investigations, calculations, material selection, scenario modelling and the preparation of drawings.

Contribution: laid the foundation for the safe implementation of the project, mitigated against the risks of degradation, as well as accounted for seismicity and infiltration.

Activity B: Construction

Objective: erection of disposal modules and associated infrastructure.

Scope: earthworks, installation of engineered barriers, concreting and the installation of monitoring systems.

Contribution: physical realisation of design solutions, ensuring tightness and stability.

Activity C: Waste Disposal

Objective: safe emplacement of VLLW in the modules.

Scope: placement of waste packages, backfilling with sorbent material, sealing and formation of protective layers.

Contribution: provision of long-term isolation of waste from the biosphere.

Activity D: Quality Assurance

Objective: control of compliance of all activities with safety requirements and regulations.

Scope: audits, inspections, documentation, material control and verification of processes.

Contribution: assurance of reliability, transparency and compliance with international standards.

Activity E: Commissioning

Objective: verification of facility readiness for safe operation.

Scope: system testing, preparation of permits and acceptance of the facility.

Contribution: confirmation of compliance with the design, regulations and licensing requirements.

Activity F: Monitoring and Oversight

Objective: ensure that the burial campaigns are carried out safely and securely.

Scope: control of barrier conditions, radiation background and water media.

Contribution: ensures that the burial campaigns stay within scope, schedule and budget, as well as provides provisions for long-term institutional control.

1.3.2. Schedule and key stages

The schedule and key stages (factual) of the three burial campaigns that have been undertaken to date, including the hot tests report agreed and permit for industrial operation, as well as the projected date up to which future campaigns will be carried out, **can be seen in the below list**:

- **Campaign 1**: 2022-07-18 → 2023-07-04 (packages placed: RAP-N 154; RAP-S 1 354).
- **Campaign 2**: 2023-07-03 → 2023-12-29 (RAP-N 154; RAP-J 10; RAP-B 327; RAP-S 520).
- **Campaign 3**: 2024-08-21 → 2025-04-24 (RAP-N 154; RAP-J 56; RAP-B 292; RAP-S 536).
- **Hot tests report agreed**: 2025-06-12; Updated SAA agreed: 2025-04-28.
- **Permit for industrial operation**: 2025-06-30.
- **Programme horizon**: campaigns planned up to ~2038, followed by ~100 years of institutional control (active then passive).

Key stages:

- **design**: development of conceptual and technical solutions,
- **construction**: erection of modules and installation of engineering systems,
- **disposal**: emplacement of waste, sealing and formation of protective layers,
- **commissioning**: testing, licensing and acceptance,
- **monitoring and oversight**: control of barrier condition, radiation background and water media.

The burial campaigns are a comprehensive engineering and organisational initiative aimed at ensuring **long-term safety**, **security** and **sustainability** of the disposal system. This also involves provisions for long-term **institutional control**, summarised below.

Institutional Control Plan - Summary

Phases: active care → passive care over ~100 years after operational closure.

Owner: INPP (or successor) maintains monitoring, access control and records.

Reviewers: Periodic safety review every 10 years; cap / cover inspection **annual**; well network **quarterly**; vegetation management **seasonal**.

Records: retention of package / WAC data, environmental / radiological monitoring datasets and maintenance logs for the full control period.

1.3.3. Processes, methods and tools

The selection and application of effective processes, methods and tools are critically important for successful project implementation, safety assurance and regulatory compliance.

The following approaches were applied during the burial campaign project:

- **radionuclide transport modelling**: use of AMBER software to evaluate scenarios of normal evolution, barrier degradation, accidents and intrusions.
- **geotechnical and hydrogeological investigations**: the determination of soil composition, aquifers and infiltration affecting design choices.
- **scenario analysis**: the development of conceptual models of radionuclide migration, mathematical modelling and dose analysis.
- **monitoring systems**: wells, dosimeters, spectrometers, TLDs, control of liquid effluents and automated data acquisition systems.
- **quality assurance programme**: materials control, documentation, verification, standardised procedures and agreement with the Client.

The methods applied ensured a high level of technical substantiation, compliance with international standards and robustness of solutions, critical for nuclear facilities.

1.3.4. Organisational roles, responsibilities and human factors

The role of personnel and organisational structure in complex infrastructure projects, especially in the nuclear sector, is pivotal. Effective coordination, allocation of responsibilities and staff training directly influence safety and successful implementation.

Core aspects of organisational roles, responsibilities and human factors, i.e. team composition, role allocation, communication and interaction, staff training and human factors are summarised below.

Team Composition

Designers, Engineers, Contractors, Radiation Protection Specialists, Operators and Quality Managers were involved in the project. Management was carried out through a partnership structure including the Client and contracting organisations.

Role Allocation

- The Client supervised conformity of design solutions with regulatory requirements.
- Contractors were responsible for the execution of construction, installation and operational activities.
- The Quality Manager defined control activities and monitored their implementation.

Communication and Interaction

- Monthly progress meetings were organised.
- Working meetings were held to resolve technical issues.
- Continuous communication between the Client and the Project Manager ensured prompt response to emerging problems.

Staff Training

- Personnel undergo training in radiation protection, technical procedures and equipment operation.
- Standardised procedures and instructions were applied, including visual inspection of packages and containers.

Human Factors

Human factors, such as qualifications, interactions and responsibilities, played a decisive role in ensuring quality, safety and timely project delivery.

1.3.5. Regulatory and licensing aspects

Compliance with regulatory requirements and obtaining the necessary licenses is the foundation of legitimacy and safety of nuclear projects. It ensures confidence on the part of regulatory authorities and the public. In the context of the burial campaign, the applicable regulatory documents, licensing and approvals, as well as compliance control, can be seen below.

Applicable Regulatory Documents

- **National standards**: VD-RA-01-2001,
- **European directives**: Council Directive 96/29/Euratom,
- **International standards**: IAEA Safety Series No. 115, SSR-6,
- **Methodological guidance**: IAEA-TECDOC-1077.

Licensing and Approvals

- **Permits** obtained for construction, operation and disposal of waste.
- **Certifications** received for radiation monitoring, fire protection and power supply systems.
- **Compliance with functional** and **regulatory requirements** confirmed in reports.

Compliance Control

- Included **analysis of critical elements**, **operational risks** and **maintainability**.
- **All systems underwent engineering assessments** and conformed to safety requirements.

The project fully complied with regulatory requirements, ensuring legal, technical and operational safety at all stages of the landfill facility life cycle.

1.3.6. Quality

Quality control in nuclear projects is not a mere formality but a guarantee of reliability, safety and robustness of solutions. It covers all stages from design to operation.

A summary of the main quality assurance measures and approach to documentation employed during the burial campaigns can be seen below.

Quality Assurance Measures

- The **quality programme**, agreed with the Client, covered design, manufacturing, construction, installation and commissioning. It **included materials control**, **documentation**, **process verification**, plus internal and external **audits**.
- The **Quality Manager monitored the implementation of all activities**, as well as identified and resolved any issues.

Documentation

- All processes were recorded in reports, protocols and as-built documentation.
- Standardised forms were used, including visual inspection of packages and containers.

The quality system ensured compliance with the design, reliability of solutions and confidence on the part of regulatory authorities and the public.

2. BURIAL CAMPAIGNS

This section describes how the VLLW burial campaigns (projects B19-1, 2 and 3) were planned and executed in practice. It covers the operational set-up, construction of the engineered barriers, waste acceptance and emplacement, safety measures and monitoring arrangements, challenges encountered and the solutions applied, as well as performance results.

Supporting evidence (such as acceptance sheets with X/Y/Z, QA protocols, monitoring logs, regulator correspondence and campaign reports) is maintained in INPP internal project records and is cited here only where necessary to explain the lessons learnt.

2.1. Challenges and difficulties encountered plus solutions

The main challenges encountered during commissioning, construction and operation of the B19-2 landfill facility have been summarised, together with the solutions applied and their observed effects.

2.1.1. Lack of suitable gravel

Description

- The project envisaged using 4 - 8 mm gravel for the drainage layer of the landfill engineering barriers.
- Market analysis in Lithuania revealed that no gravel meeting these specifications was available.
- The only offers were for 4 - 16 mm gravel.

Solution

- Modification of gravel requirements.
  - It was decided to use 4 - 16 mm gravel.
  - This improved the drainage properties of the layer and its compatibility.
  - Using this gravel fraction only enhances drainage and allows better compaction.

2.1.2. Conflicting requirements for the geomembrane

Description

- The technical design contained conflicting requirements for the HDPE geomembrane.
- The project specified that the HDPE should be textured, but the specification referred to smooth HDPE.
- The requirement for 700% elongation was impossible for membranes with double-sided texturing.

Solution

- Clarification of geomembrane requirements
  - The technical design was revised to specify only the required characteristics for double-sided textured HDPE.
  - Conflicting requirements in different parts of the technical design were harmonised.

2.1.3. Strict requirements for topsoil

Description

- The pH (6.5 - 7) and humus content (2 - 3%) requirements were too strict.
- As a result, no offers were received during procurement.

Solution

- Expansion of topsoil specification range
  - Broader ranges were established: pH (4 - 9) and humus content (minimum 1%).
  - Soil type requirement was removed.
  - This enabled a successful tender and procurement of the required topsoil.

2.1.4. Lack of suitable sand description

Description

- Medium-grain sand (0.1 - 1 mm fraction) was not available on the market.
- The primary purpose of the sand was to fill voids in the package stack and ensure stack stability.

Solution

- Modification of sand requirements
  - It was decided to use 0 - 1 mm fraction sand.
  - This improved sand flowability and void-filling capacity.
  - Increasing the fine fraction does not reduce void-filling ability but improves flow and promotes better compaction.

2.1.5. Decision to use in-house expertise or a contractor for the first burial campaign

A key decision was faced when planning the first campaign for the B19-2 repository, i.e., whether to deliver the work using INPP's own staff or hire an external contractor? To make an informed choice, INPP carefully compared the pros and cons of both options. The following approach was taken:

a. Evaluation of personnel expertise

- INPP employees are experienced in handling radioactive waste and hold the necessary licenses for working in ionising environments. And their quality management system is well-established
- However, they lack construction experience and some certified specialists. Diverting internal resources could negatively impact other critical INPP projects.

b. Evaluation of contractor's expertise

- Contractors pose the prospect of qualified personnel and are more construction orientated.
- A potential drawback of using external contractors, even those experienced in radiological environments, is that they may adopt a conservative approach in areas with potential exposure, which can slow execution. They also require additional licensing and radiological training, introducing lead times and costs that can affect schedule and budget.

c. Cost

Another major factor to consider is that INPP could have reduced expenses by using their own equipment and avoiding contractor markups. Contractors, also, might increase costs due to their margins and concerns about contamination etc.

d. Procurement and equipment

INPP had a rare 25 tonne loader in their possession, but it was thought that using it would delay other operations. And while contractors could use their own equipment, renting a similar loader is expensive and difficult.

INPP acknowledged that both options presented significant advantages and drawbacks. The final decision had to balance resources, timelines, risks and costs.

After evaluating all available resources, technical capabilities, risks associated with renting and purchasing equipment, and the qualifications of their personnel, **INPP decided that the most effective solution would be to carry out the campaign using INPP staff**. This approach allowed INPP to maintain control over the process, minimise costs and to make the most of the equipment they already had.

2.1.6. Equipment used for the repository module construction campaign

As INPP prepared to construct the repository module, they assessed the available equipment and determined what could be used, rented or purchased.

The main workhorse was the Kalmar DCD250-12 forklift, with a lifting capacity of 25 tonnes. It was transferred from project B19-1 and used for handling packages. The forklift was fully operational, recently serviced and had spare tires.

For handling soft containers and compressed bales, a 1.5 tonnes forklift with a special side grip was used. It was part of the process but required some maintenance.

The EK-14 backhoe loader from the INPP transport department was brought in for earthworks. Despite lacking a windshield, it was functional and recommended for use.

A 40 tonnes truck crane was used to install heavy packages and bales. Equipped with a special grip, it was in working condition and suitable for the task.

The TO-8B3 front loader was also utilised in good condition and capable of moving materials efficiently.

MAZ dump trucks of various models, each with a capacity of up to 20 tonnes, were available and met the project's needs.

Some equipment, such as **soil compactors, density measuring devices, welding machines and fire safety gear**, were not available and were listed for procurement.

In summary, INPP's existing resources were leveraged as much as possible, supplementing them with rentals and purchases to ensure the successful execution of the construction campaign.

2.1.7. Technical regulation

The operation of the repository is strictly regulated. Every activity, from transporting waste to its burial, follows a technological regulation approved by the plant's management and coordinated with regulatory authorities.

Work at the repository is carried out in **campaigns**, **each lasting 2 to 3 months**. Waste is packed into special containers (ISO containers, FIBCs and bales) and delivered to the site. There, it is stacked, covered with sand and sealed with engineered barriers.

Safety is of paramount importance. **The repository is equipped with systems for radiation monitoring, fire protection, power supply, lighting, communication and physical security**. All systems are regularly inspected, maintained and upgraded. Personnel are trained and operate under strict procedures.

Radiation control is performed using dosimeters and spectrometric analysis. In the case of emergencies, such as container drops or fires, clear protocols are in place to contain and mitigate the consequences.

Every step is documented. Department heads are responsible for compliance and independent audits confirm adherence to the regulation.

Thus, INPPs ensures the safe handling of radioactive waste, protecting people and the environment step by step.

2.1.8. Change log (campaigns 1–3)

Change logs from the three campaigns can be seen in Table 3 below.

Table 3. Change logs from the three past burial campaigns

Item	From → To	Why (justification)	Evidence
Drainage gravel fraction	[original spec] → 4 - 16 mm	Market availability; hydraulic capacity unchanged by calc; fewer QA rejects	QA batch logs; calc note; change-control ID CC-DG-01
HDPE liner role	"functional barrier" → protective layer for GCL	HDPE protects GCL during construction / handling; no separate safety credit	Design note; barrier functions table
Topsoil parameters	Tight fixed value → acceptable ranges (pH, humus, grain size) (see section 2.1.3)	Agronomic stability and erosion control; alignment with field trials	Field trials report; QA acceptance

2.2. Structure of the VLLW landfill's single disposal module

A schematic of the VLLW landfill's single disposal module can be seen below in Figure 4.

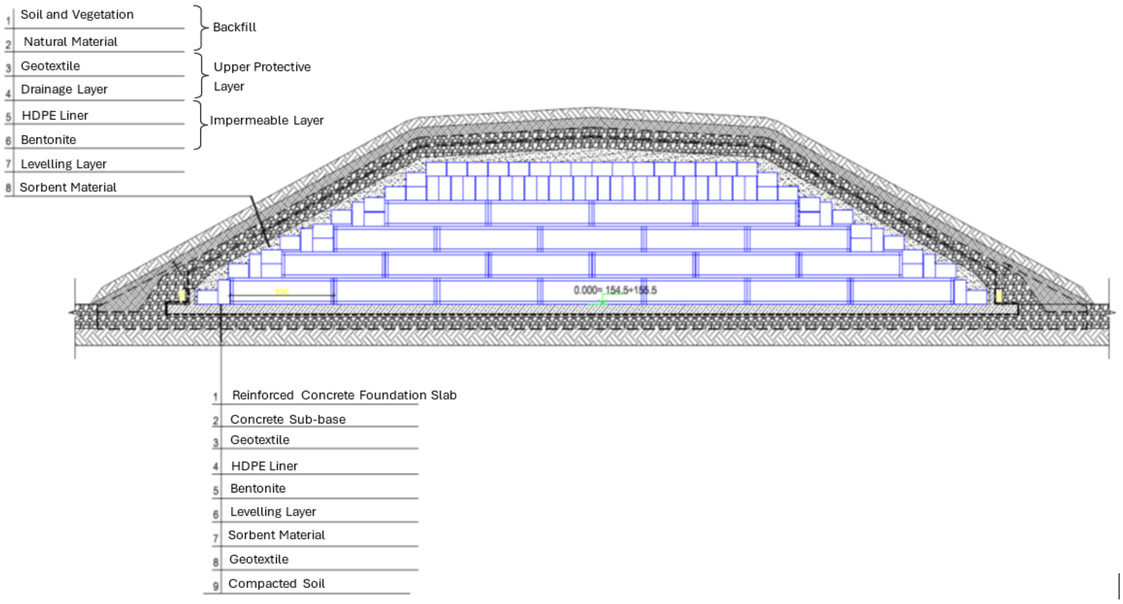

Figure 4. Schematic of the structure of the VLLW landfill´s single disposal module (engineered barriers)

> The **High-Density Polyethylene** (**HDPE**) liner in this system **primarily protects the Geosynthetic Clay Liner** (**GCL**) **during construction** and handling. However, it is not credited as a standalone safety barrier in the safety assessment.

The **HDPE liner** is a synthetic polymeric geomembrane (waterproofing material) installed on surfaces where it is necessary to contain chemical products or water contaminated with them, preventing infiltration into the subsoil. It is manufactured from HDPE resin.

The main characteristics of the HDPE liner are as follows:

- **density**: 945 kg/m³,
- **thickness**: 2.5 mm,
- **tensile strength**: 350 N (in accordance with **ASTM D1004**),
- **elongation at break**: 700%.

2.2.1. Foundation

Based on the analysis of geological investigations, it was determined that weak soils predominate at the site proposed for the construction of the disposal modules. Therefore**, the foundation of the landfill-type repository modules was designed to consist of**:

- **compacted soil**,
- **geotextile material**,
- **a drainage layer**,
- **isolating materials** (bentonite and HDPE liner, intended to protect the soil against water penetration and radionuclide migration),
- **concrete bedding**,
- **a reinforced concrete slab**.

Figure 5. The foundation at different stages of development

The foundation ensures the stability of the radioactive waste packages placed on it. It was also designed to withstand potential soil movements (**the base slab** of the disposal modules **is engineered for a seismic load** corresponding to a **magnitude-7 earthquake**, thereby **ensuring the integrity of the module for more than 100 years**).

Furthermore, **if necessary**, **the module foundation can function as a flat reservoir for the collection of rainwater** (if any accumulates).

To meet the above-mentioned requirements, the repository foundation was designed as a self-supporting reinforced concrete slab (divided into three parts by expansion joints), with a slope in the direction of waste emplacement (i.e., from east to west).

2.2.2. Surface layers (engineered barriers)

Different surfaces (engineered barriers), provide multiple layers of protection.

Backfill and sorbent material: sand was used to provide stability to the radioactive waste and also serves to retard radionuclide migration (see Figure 6 for an example of the sand utilised).

Figure 6. An example of the sand utilised for backfill and sorbent material

Levelling layer: composed of sand and gravel. This layer eliminates surface irregularities of the module and provides mechanical support to the overlying layers.

Impermeable layer (Bentonite + HDPE liner): designed to protect the repository from precipitation infiltration (the HDPE liner is placed to protect the bentonite). The potential for water leakage through this layer is practically negligible. Due to its plasticity, the layer is frost-resistant.

Upper protective layer: intended to shield against ionising radiation emitted from the waste packages in the module, as well as to protect against root penetration, animal intrusion, unforeseen external impacts and excessive precipitation that could cause erosion of the upper repository layers. Erosion is prevented by covering the repository surface with perennial vegetation.

The **upper protective layer consists of**:

- **a drainage layer** (gravel),
- **geotextile material** (geotextile is a generic term covering nonwoven fabrics and products made thereof).

2.2.3. Cover system (capping / overburden)

The final cover consisted of a layer of natural material and a layer of soil and vegetation (pictured in Figure 7).

Figure 7. Covered landfill

The natural material layer composed of locally sourced soil. The soil and vegetation layer consisted of planted topsoil. The repository surface was planted with carefully selected vegetation (shallow-rooted, resilient under adverse conditions, etc.). During the institutional control period (see section 1.3.2), the vegetation cover will be properly maintained (timely mowing, removal of alien species, etc.).

2.3. Layout of disposal modules and other on-site facilities

The design of the disposal modules represents an above-ground facility, where radioactive waste placed in standard 20-foot ISO half-containers, in 1 m³ bales, and in 1 m³ reinforced plastic containers, is emplaced in multiple tiers on a load-bearing concrete foundation and isolated from the environment by several layers of natural and engineered materials.

As presented earlier and repeated to provide context, the layout of the disposal modules and other on-site facilities can be seen in Figure 8 above, **its key features** of which **are denoted by the following numbers**:

1. **disposal modules** of the landfill facility,
2. **fence** of the disposal module area,
3. **sites of complexes B1** (new Interim Spent Fuel Storage Facility (**ISFSF**)) and B3/4 (new Solid Waste Treatment and Storage Facility (**SWT&SF)**),
4. **ramps** for vehicle inspection,
5. **control** (security) **building**,
6. **facility for collection of domestic wastewater**,
7. **underground tanks** for collection of rainwater,
8. **welfare / auxiliary premises** (to be periodically relocated in the direction of landfill filling),
9. **fuelling point for vehicles**.

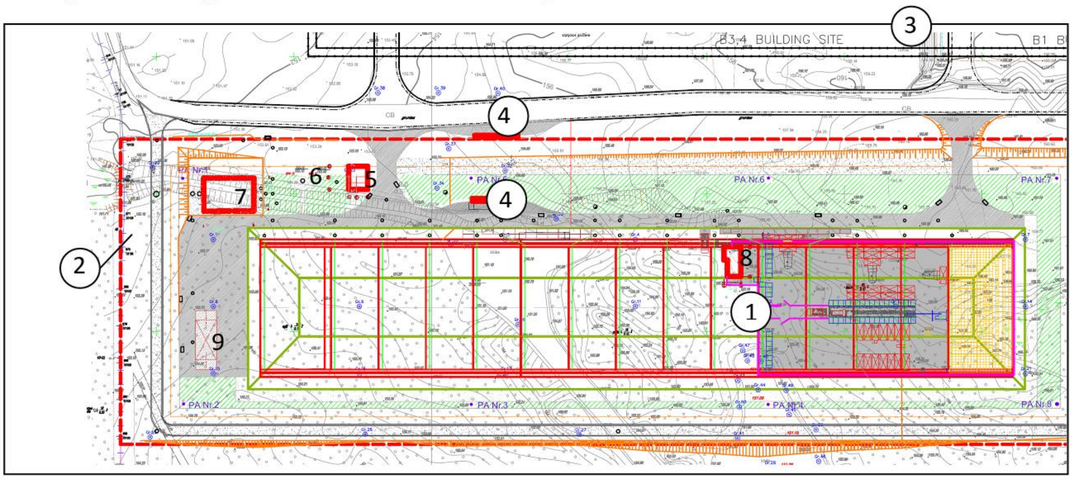

Figure 8. Layout of the disposal modules and other on-site facilities

2.4. Bentonite geosynthetic clay liner (GCL)

During the installation of the bentonite liner (bentonite mat / GCL), shown in Figure 9, granular bentonite was applied to seal the overlap joints (certain types are supplied with a sealing layer pre-applied at the factory).

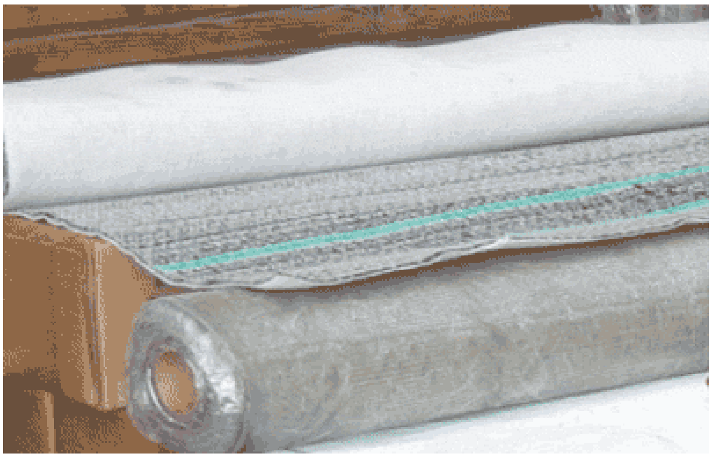

Figure 9. Snapshot of a bentonite mat / GCL

The **main advantages of bentonite-based materials** are as follows:

- **high anti-filtration properties**,
- **applicability under complex hydrogeological conditions**, withstanding hydrostatic pressure up to 0.7 MPa,
- **self-healing capacity** due to significant swelling upon hydration,
- **long-term durability** of the waterproofing system, resulting from the stability of properties over time,
- **environmental compatibility**,
- **high resistance to chemically aggressive substances** (oil, lubricants, gasoline, etc.),
- **unlimited number of “hydration–dehydration” cycles**.

The **main characteristics of bentonite-based materials** are as follows:

- **permeability coefficient**: not exceeding 1.0 × 10^{-8} cm/s (in accordance with **DIN 18130** / **ASTM D5887**),
- **tensile strength**: 330 N (in accordance with **ASTM D6496**),
- **installation temperature range**: –30 °C to +50 °C,
- **bentonite content**: 4.8 to 4.96 kg/m² (in accordance with **EN 14196**),
- **material thickness**: 5.5 to 7 mm (**EN ISO 9863-1** / **EN 964-1**).

2.5. Geotextile material

Due to the optimal combination of its characteristics, geotextile performs the key functions of separation, reinforcement, filtration, drainage, as well as combinations thereof, in applications such as drainage system construction, land development and related engineering works.

Figure 10. Photo of geotextile material

The structure of the material provides excellent mechanical strength and filtration properties.

Table 4. Descriptions of the geotextile material structure and functions

Cover structure	Function
Upper protective layer + slope stabilization mesh + local soil	The upper protective layer provides the soil cover for perennial vegetation to be planted. In order to ensure the stability of the underlying layers, to control surface erosion, and to strengthen and reinforce the plant root zone, a special slope stabilization mesh (e.g., Secumat type) is applied.
Geotextile + gravel	The gravel layer is used as a drainage layer. Its primary function is to drain water and to minimise infiltration into the underlying layers. It also provides stability (a base) for the overlying layers. Geotextile is mainly applied to separate the different layers during installation and is not considered in safety assessment.
Geotextile + high-density polyethylene (HDPE) liner + bentonite liner	Provides protection against water infiltration into the underlying layers (sand, sand + gravel) and the waste. The most essential barrier for water protection is the bentonite layer. HDPE liner is primarily intended to protect the bentonite liner during construction and is not considered in safety assessments. Geotextile is mainly used to separate the different layers during installation and is not considered in safety assessments.
Sand + gravel (i.e., levelling layer)	Serves as a stable base for the overlying layers.
Sand (i.e., backfill and sorbent material)	Provides stability to the radioactive waste (as well as to the disposal module structure) and acts as a sorbent material.

Table 5. Descriptions of the repository´s engineered barrier (N°), safety functions and period of performance

Nº	Engineered barrier (N°)	Safety function	Period of performance**
1	**Upper protective layer**	Protection against gamma radiation	Operational period and institutional control
	Prevention of root penetration, frost protection	Operational period and institutional control	
	Prevention of inadvertent human intrusion	Post-institutional control period	
2	**Impermeable layer (hydro-insulation layer)**	Prevention of infiltration of atmospheric precipitation and root penetration	Operational period and institutional control
3	**Backfill and sorbent material**	Protection against gamma radiation	Operational period and institutional control
	Retardation of radionuclide migration (sorption)	Institutional and post-institutional control periods	
4	**Repository foundation**	Prevention of radionuclide release by maintaining the integrity of engineered barriers under normal conditions and incident scenarios	Operational period and institutional control
	Retardation of radionuclide migration (sorption)	Institutional and post-institutional control periods	
	Prevention of groundwater ingress into the repository	Operational, institutional and post-institutional control periods	
5	**Soil**	Prevention of groundwater ingress into the repository	Operational period and institutional control

2.5.1. Barrier functions and performance window

Table 6 below shows the main barrier layers and performance windows with respect to primary safety functions and secondary functions.

Table 6. Barrier functions, primary safety functions, secondary functions and performance window

Barrier layer (top→bottom)	Primary safety function(s)	Secondary function(s)	Performance window
Topsoil & vegetation	Erosion control, evapotranspiration	Visual integration	Operation, post-closure
Protective soil	Shielding of liner/GCL, drainage support	Load distribution	Operation
Drainage layer	Runoff control, pore-pressure relief	Gas conveyance (if present)	Operation, post-closure
Geomembrane / low-k layer	Infiltration barrier	Mechanical protection of GCL	Operation, post-closure
GCL (bentonite)	Low permeability, sorption	Limited self-healing	Operation, post-closure
Levelling / base layer	Even bearing, settlement control	Filtration	Construction, operation
Reinforced concrete slab	Structural base, separation	Inspection surface	Construction, operation

2.5.2. Materials chemistry envelope (acceptance ranges)

Table 7 shows the materials chemistry envelope (acceptance ranges) with respect to key property, acceptance envelope and rationale.

Table 7. Materials, key properties, acceptance envelope and rationale

Material	Key property	Acceptance envelope	Rationale
Topsoil	pH / humus / grain composition	**[min–max] / [min–max] / [spec]**	Vegetation & erosion control
Drainage gravel	Gradation / fines	**[spec: 4–16 mm] / [max fines %]**	Hydraulic capacity; anti-clogging
GCL bentonite	Swell index / fluid loss	**[min–max] / [max]**	Low permeability
HDPE liner	Texture / elongation	**[texture type] / [min %]**	Handling protection of GCL
Geotextile	Mass per unit area / puncture	**[g·m^{-2}] / [min]**	Protection & separation

2.6. Safety measures taken and risks identified

The overall **safety concept** is **based on a multi-layer protection system** combined with procedural barriers. This ensures that if one layer or line of defence is temporarily stressed, for example, during heavy rain, the other layers continue to provide protection and maintain system integrity.

2.6.1. Multi-Layer System — "Each layer has its role"

Table 8 below elaborates each layer's function / purpose.

Table 8. Descriptions of the multi-layer system with respect to function / purpose

Layer	Function / Purpose
Protective cover	Prevents erosion, provides γ-shielding and serves as a root barrier to protect underlying structures.
Drainage layer + geotextile	Removes surface and infiltrated water, separates structural layers and prevents clogging.
GCL + HDPE geomembrane	Acts as the primary infiltration barrier; HDPE protects the GCL during installation and early settlement phase.
Levelling layer (sand / gravel)	Provides a stable even surface for upper layers and ensures proper drainage paths.
Infill / sorbent layer	Sand placed between packages to absorb liquids and stabilise the stacks.
Reinforced concrete (RC) foundation	Ensures overall structural integrity, provides seismic resistance, and facilitates drainage collection.

2.6.2. Safety by lifecycle phases

The following outcomes were observed when safety was considered by lifecycle phases:

- radiological conditions remain **stable**,
- **no releases** to the environment have been recorded,
- **dose rates and contamination** levels are consistently below regulatory limits,
- **part of the operational area** was successfully reclassified from **controlled** to **supervised**, optimising operation and maintenance needs.

These controls are verified through routine environmental and radiological monitoring: wells, runoff from the concrete slab, air / precipitation sampling, TLD-based dose monitoring and meteorological observations. Performance of these activities is tracked via KPIs (see section 2.7), in particular the monitoring and response efficiency KPI, which measures both on-time completion of required measurements and the median time-to-action when a trigger occurs.

Table 9 elaborates the concept of safety by lifecycle with descriptions of key safety measures, risk factors and mitigation strategies.

Table 9. Safety by lifecycle phases with key safety measures, risk factors and mitigation strategies

Phase	Key Safety Measures
Design & Procurement	• Validate WAC. • Perform early market scan to ensure realistic material specifications and tolerances. • Adjust specifications through change-control if necessary.
Construction	• Conduct batch-based QA testing according to EN/ASTM standards. • Record acceptance checkpoints layer-by-layer. • Implement HS inductions, PPE use and personal dosimetry. • Verify all lifting and compaction equipment before use.
Operation	• Accept only waste packages meeting WAC (X/Y/Z and α limits; surface dose and contamination), per the X/Y/Z method (see “WAC and X/Y/Z method (self-contained)” under the section “Approach”). • Carry out scheduled environmental and radiological monitoring (wells, runoff, air / precipitation, TLDs, meteorological stations). • Maintain cover, drainage and access systems.
Post-Closure	• Ensure institutional control through regular inspections and maintenance of cover and drainage. • Continue environmental surveillance on predefined schedule.
Risk Factor	**Mitigation Strategy**
Specification - market mismatch	Early supplier engagement, market scan, harmonised specifications, and structured change-control.
Infiltration or surface erosion	Combined GCL + HDPE barrier, drainage control, reinforced vegetation cover, stabilising mesh.
Operational or intrusion scenarios	Strict WAC compliance, fenced and controlled access, continuous supervision.
Human or equipment-related incidents	Training, standardised procedures, emergency drills, individual dosimetry and periodic audits.

Waste packages are only accepted for emplacement if they comply with the WAC, including X/Y/Z indices and alpha activity limits, as calculated according to the X/Y/Z method defined in “WAC and X/Y/Z method (self-contained)” under the “Approach” section and confirmed prior to emplacement. Dose rates and surface contamination at the package are also checked against limits.

These practices are **consistent with ALARA principles**: individual and collective doses remained low, no releases were observed and part of the area could be reclassified from “controlled” to “supervised”, allowing for the optimisation of future operations.

2.6.3. Scenario-to-control map

Table 10 shows the three most pertinent safety scenario family members mapped against their typical drivers, controlling barrier / controls and a brief description of why it dominates.

Table 10. Scenario-to-control map including typical drivers and why it dominates

Scenario family	Typical drivers	Controlling barrier / control	Why it dominates
Operational (handling)	Contact dose, smear contamination	Handling procedures, PPE, **dose/contamination limits, Z-sum**	Worker protection is first line; Z governs short-lived nuclides
Evolution (leaching)	Infiltration, transport	Cover system, low-k liner / GCL, drainage, **Y-sum**	Long-term migration control
Inadvertent intrusion	Drilling / earthworks	Cap thickness, RC slab, **X-sum**	Limits potential intruder dose

2.6.4. Monitoring plan — triggers and actions

Table 11 shows the monitoring plan for four different important parameters (groundwater activity, slab runoff, ambient doss rate and air / precipitation) with respect to their locations / frequencies of measurement, triggers and actions.

Table 11. Monitoring plan for four main parameters with location / frequency, trigger and action

Parameter	Location / frequency	Trigger	Action
Groundwater activity (key nuclides)	Perimeter wells W-xx / **quarterly**	Baseline + **site action level**	Confirmatory sample → root-cause → corrective works on cover / drainage; report in KPI
Slab runoff	**Monthly**	> **[threshold]**	Inspect drains, clean, retest; log deviation
Ambient dose rate	**Monthly routes**	> **[site level]**	Area review; shielding / route change; note to HS/RP
Air / precipitation	**Monthly**	> **[threshold]**	Source check; housekeeping; repeat after action

2.6.5. Assumptions and conservatisms (model)

The **assumptions and conservatisms below were recorded as applicable during the campaigns**:

Infiltration through the cap bounded conservatively for post-closure cases.

Receptor exposure parameters reflect conservative habit patterns.

Transport parameters set to upper-bound uncertainty ranges.

Sensitivity shows safety functions remain effective within the adopted bounds.

2.7. Key performance indicators

The different KPIs, what they measure and the key metrics / example indicators are shown in Table 12. The purpose for using the KPIs, method of KPIs generation and approach to reporting the KPIs are summarised below:

Purpose: The KPIs are used to demonstrate that the burial campaigns are being delivered safely, efficiently and in line with regulatory expectations. They track safety / compliance, schedule reliability, cost / schedule control and the organisation's ability to respond to change.

Method: KPI values are generated from routine operational records, including: incoming material QA logs, package acceptance sheets with X/Y/Z, monitoring and dosimetry logs, procurement change-control records and project controls (schedule / cost baselines, EV /AC /PV).

Reporting: KPI summaries are reviewed during and after each campaign.

Table 12. KPI groups, what they measure and key metrics / example indicators

KPI Group	What It Measures	Key Metric / Example Indicator
1. Material Conformance	Ensures that supplied construction materials (drainage, GCL, HDPE, geotextiles) meet specifications without rework.	% of material batches accepted on first submission.
2. Waste Acceptance Compliance	Confirms that all waste packages meet the defined WAC limits before placement.	• % of packages passing criteria X < 1, Y < 1, Z < 1 without corrections. per the X/Y/Z method (see "WAC and X/Y/Z method (self-contained)" under "Approach") • Side indicator: share of cases where $1 < Y \leq 10$ but average $\bar{Y} < 1$ per module.
3. Monitoring and Response Efficiency	Tracks environmental and radiological monitoring and how promptly corrective actions are taken.	% of scheduled measurements completed on time. Median time-to-action after any exceedance.
4. Personnel Dose Control (ALARA)	Evaluates radiation exposure to ensure doses remain "As Low As Reasonably Achievable".	Average individual and collective dose per campaign.
5. Procurement Responsiveness	Measures how quickly the supply chain adapts to updated technical requirements.	Median number of days from specification - change approval to first compliant delivery.
6. Project Performance (EVM)	Reflects cost and schedule performance using Earned Value Management (EVM) indices.	CPI = 1.31 (cost efficiency), SPI = 1.00 (on schedule); budget vs actual trends.

3. KEY TAKEAWAYS

Specification harmonisation plus early market scan reduced QA rejections and delivery delays.

Standardised layer QA (checklists, photo logs, weekly audits) reduced rework and made quality fully auditable.

Buffer pre-checks at B19-1 and pre-staged material pads reduced crane idle time and improved on-module flow.

INPP's mixed in-house resources plus targeted rentals allowed the work to be delivered on schedule and within cost expectations.

A regulator milestone tracker with buffers supported on-time licensing, including the industrial operation permit on the 30th June 2025.

Organisational impact

INPP assessed the project's effectiveness and its strategic value for safe decommissioning and long-term waste management. **Direct organisational benefits include**:

- **enhanced safety** of VLLW management,
- **compliance** with international requirements and standards,
- **reduced risks** to personnel and the environment,
- **preparedness** for a ~100-year period of institutional control,
- **centralised waste / package data** within Project B17.

Conclusion

The **project objectives were achieved**. **Safety**, regulatory compliance and readiness for the long-term institutional control phase were ensured.

3.1. Lessons Learnt

Five lessons learnt (LL) were recorded in total. The situation, decision taken, effect observed and recommendation have been described for each one.

#LL-1 Market ≠ initial specifications

Decision taken: harmonise specifications with real market availability; define tolerances; use controlled change process.

Effect observed: fewer QA rejections and fewer delivery delays.

Recommendation: perform early market scan and build realistic tolerances into procurement specs up front.

#LL-2 Layer QA inconsistent between crews

Decision taken: introduce one-page QA checklists per layer + photo logs + weekly audits.

Effect observed: transparent auditable quality and less rework.

Recommendation: keep mandatory checklists and weekly audits for every layer.

#LL-3 On-site bottlenecks (crane / forklift / staging)

Decision taken: move acceptance checks to the buffer area (B19-1); stage materials on prepared pads.

Effect observed: smoother flow; less crane idle time.

Recommendation: keep buffer checks and pre-staged pads as standard practice.

#LL-4 Peaks in specialised equipment / skills

Decision taken: base load covered by INPP resources; peak load covered by targeted rentals and focused training.

Effect observed: schedule kept without overspend.

Recommendation: maintain 8-week rolling resource forecast and pre-book peak equipment.

#LL-5 Regulator approval cycle delaying closure

Decision taken: milestone tracker with buffer and ownership per submission.

Effect observed: permit delivered on the 30th of June 2025 as planned.

Recommendation: keep a regulator milestone tracker with buffer for critical submissions.

3.2. Recommendations

Six global recommendations (Rs) have been provided based on experience of performing the past three burial campaigns with a few informing future similar works.

#R-1 Lock specification harmonisation early

Adopt market-available ranges (e.g. drainage 4 - 16 mm; HDPE texture / elongation; topsoil pH / humus) and maintain a standing change-control template.

#R-2 Standardise layer QA

Use one-page checklists, photo logs and weekly audits for each layer (inputs → steps → checkpoints → acceptance → evidence). This keeps quality auditable and reduces rework.

#R-3 De-bottleneck logistics

Perform pre-checks in a buffer area (B19-1), stage materials on prepared pads near the module and maintain a shared crane / forklift resource calendar to avoid idle time.

#R-4 Manage resource peaks proactively

Keep a rolling 8-week resource / equipment forecast, pre-book rentals for peak periods and provide targeted operator training to avoid delays.

#R-5 Maintain regulatory milestone tracking

Track each submission and approval gate with defined owners and buffers (e.g. hot tests, SAA update, industrial operation permit). This supports on-time licensing.

#R-6 Keep a lightweight KPIs dashboard

Use a concise KPIs dashboard in the body of the report and archive the detailed data tables and raw logs in an annex(s). Give each KPI a simple traffic-light status (green / amber / red).

4. REFERENCES

1. Internal safety basis for B19-2 (INPP, internal)
Defines engineered barrier functions and the Waste Acceptance Criteria (WAC), including the X/Y/Z methodology and package-level operational limits (dose rate, surface contamination, long-lived alpha). (This KP embeds the relevant formulas and limits in Section “WAC and X/Y/Z method”.)

2. B19-2 design and construction documentation (INPP, internal)
Engineering design of foundation, drainage, GCL, HDPE, geotextile and protective cover; systems for radiation monitoring, fire protection and power supply; as-built records for Campaigns 1–3.

3. Technological Regulation / Operating procedures for B19-2 (INPP, internal)
Acceptance, handling and emplacement procedures; emergency response (drops, fire); supervision, PPE and dosimetry requirements.

4. Licensing dossier and permits for B19-2 (VATESI/INPP, internal)
Hot tests agreement (12 Jun 2025), updated SAA (28 Apr 2025) and industrial operation permit (30 Jun 2025).

5. Waste package acceptance sheets and WAC conformity records (Campaigns 1–3)
Package-level X/Y/Z indices, α activity, surface dose and contamination checks for RAP-N/S/J/B.

6. Incoming material QA / conformity logs and test protocols (EN / ASTM)
Batch inspection of drainage gravel, GCL, HDPE, geotextiles, topsoil; first-pass acceptance performance.

7. Environmental & radiological monitoring records (Campaigns 1–3)
Groundwater wells, slab runoff, air/precipitation sampling, TLD dosimetry and meteorology; evidence supporting “no releases” and area reclassification to Supervised.

8. Occupational dosimetry reports (HS/RP)
Individual and collective doses; ALARA reviews.

9. Procurement change-control register and supplier communications.
Approved spec changes (e.g., drainage 4–16 mm; HDPE texture/elongation; topsoil ranges), timestamps and time to first compliant delivery.

10. Project controls / Earned Value Management (EVM) reports
PV, EV, AC, CPI, SPI and plan vs actual cost curves confirming CPI≈1.31 and SPI≈1.00.

11. External normative references
IAEA SSR-6 (Regulations for the Safe Transport of Radioactive Material); **ISO 1496-1** (Series 1 Freight Containers – Part 1: General Cargo Containers); **Council Directive 96/29/Euratom**; **IAEA Safety Series No. 115**; **IAEA-TECDOC-1077**; **VD-RA-01-2001**.