

Construction Progress and Technical Overview of the Vrbina LILW Disposal Facility near Krško, Slovenia

Miha Ašič, Sandi Viršek

ARAO – Agency for radwaste management - Slovenia
Litostrojska 58 A, Ljubljana, Slovenia
miha.asic@arao.si, sandi.virsek@arao.si

ABSTRACT

The low- and intermediate-level radioactive waste (LILW) disposal facility in Slovenia, represents a nationally significant infrastructure project for the permanent management of operational and future decommissioning waste from the Krško Nuclear Power Plant (NEK), as well as institutional radioactive waste generated in Slovenia. The facility is being developed to meet national and international safety requirements, ensuring long-term protection of people and the environment through a passive safety concept based on engineered and natural barriers.

The Vrbina facility is designed as a near-surface repository with a deep vertical silo structure. The disposal silo will have an internal diameter of app. 27 m and a depth of about 56 m, allowing emplacement of up to 990 reinforced-concrete disposal containers. Once complete, the silo will be sealed with a concrete cap and covered by a clay layer, forming a multi-barrier system consistent with international best practice for LILW disposal.

Construction of the repository is organised into three main phases. Phase 1, started in August 2023, delivered site infrastructure and physical protection of the site. Phase 2, focuses on civil works for the silo, and surface buildings. The diaphragm wall panels extend about 66 m deep to support the excavation and control groundwater. Phase 3 covers supply and installation of a portal crane and lifting equipment for safe handling and emplacement of waste containers.

As of early 2026 construction is progressing according to plan. Preparatory groundworks and hydro-insulation were completed in 2024–2025, with excavation of the silo pit reaching design depth. Concrete placement for the silo floor slab has been executed and is now followed by continuation of silo concrete works, the most technically demanding part of the project. Surface facilities including the technological and administrative buildings are under construction, and trial operation of the repository is targeted for 2027–2028.

The disposal concept utilises standardised reinforced-concrete containers designed to accommodate combinations of different waste forms. This project integrates comprehensive civil engineering with nuclear safety principles, providing Slovenia with a purpose-built long-term disposal solution that fulfils ethical and regulatory obligations for responsible radioactive waste management.

Keywords: *Low- and intermediate-level radioactive waste (LILW), Vrbina disposal facility, near-surface repository, radioactive waste management, multi-barrier system, repository construction, diaphragm wall, reinforced-concrete containers, nuclear facility in Slovenia*

INTRODUCTION

ARAO was established by the Government of the Republic of Slovenia in 1991 with the mandate to ensure the safe and permanent disposal of radioactive waste within Slovenia. ARAO currently operates three facilities:

- central interim radwaste storage facility
- the closed disposal sites for mining and hydrometallurgical tailings Boršt and Jazbec.

At present, ARAO is implementing its largest infrastructure project - the construction of low and intermediate level radioactive waste repository in Vrbina, Slovenia. The construction has been underway since mid-2023 and is divided into three phases.

Phase 1 (Lot 1) included construction of utility infrastructure, technical and physical protection systems, and the reconstruction of the Vrbina access road. These works were completed in mid-2024. This allowed the construction to proceed in the implementation of the second phase.

Phase 2 (Lot 2), currently in progress, includes construction of the disposal silo, technological and administrative buildings, and associated site infrastructure.

Phase 3 (Lot 3) will include installation and commissioning of the lifting and handling systems..

The objective of this paper is to present the construction concept, key engineering challenges, and lessons learned during the implementation of the Vrbina LILW disposal facility.

1 LOCATION

The repository site is located in Vrbina in Krško municipality. It's located in a flat gravel terrain along the river Sava, nearby are agricultural fields and orchards. The town Krško is 3,5 km NW.

In 2004, the spatial planning and siting procedure for the project was initiated. A total of twelve potential locations were evaluated based on environmental, socio-economic, safety, and spatial criteria. In addition, a comprehensive environmental impact assessment was carried out, along with a dedicated safety analysis, a conceptual design of the disposal facility, and consultations with local stakeholder partnerships. In 2009, the site was officially approved, along with the corresponding disposal concept.

In 2017, a preloading embankment was constructed at the site at an elevation of 153 m above sea level. In addition, an uncompacted humus embankment was formed alongside the preloading embankment, intended for later use in landscaping and site restoration works.



Figure 1: Location of LILW repository

2 CONSTRUCTION OF LILW REPOSITORY

2.1 Construction phase 1

A public procurement procedure for LOT 1 was conducted in 2023. It includes infrastructure & technical security establishment and the work started in August 2023. In this phase of project was build: sewage system, electric lines, telecommunications, water system was established and physical and technical security with the outside fence was completed. In this phase was also renovation of Vrbina road. The work was completed in April 2024



Figure 2: construction of phase 1

2.2 Construction phase 2

The construction of Phase 2 represents the most extensive part of the project, as it includes the excavation of the primary lining, the excavation of the silo, and the construction of the floor slab and secondary lining with all associated works. It also comprises the construction of the technological building, the administrative building and the installation of a hall above the silo, which will be the only montage steel structure. The completion of the works is planned for the second half of 2027.



Figure 3: construction of the secondary wall

2.2.1 Disposal silo

The silo is near surface construction dimensions of 27,3 m diameter and 56 m depth to the bottom slab. The thickness of the primary wall is 1,5 m and secondary wall 1 m. The primary wall is deep 66m and it's made from 10 primary and 10 secondary panels. When the primary wall was finished became excavation of the silo. Week cycle of digging was 3m, after 5th cycle they reduced to 2,5m per week. The material was excavated with two excavators and was transported to the surface with crane. On the bottom of silo is a concave shaped floor slab which measure 7 m in its thickest part. In slab is a tunnel and pool for technological wastewater.



Figure 4: construction of the floor slab

2.2.2 Technological building

The technological building represents a key operational component of the Vrblina LILW disposal facility, integrating waste handling, control, and monitoring functions within a single structure. It is designed to ensure safe and efficient handling of waste packages prior to their emplacement in the disposal silo, while maintaining compliance with nuclear and radiation safety requirements.

The building is a reinforced concrete structure with approximate plan dimensions of 58 × 15 m. The load-bearing system consists of perimeter and internal reinforced concrete walls arranged in both principal directions, providing structural stability and resistance to operational and environmental loads.

Due to variable subsoil conditions and the need to limit differential settlement, ground improvement was carried out using jet grouting techniques, with approximately 930 columns installed beneath the foundation slab. This ensures adequate bearing capacity and long-term structural stability of the facility.

The technological building includes several functional areas:

- **Container handling and temporary storage area**, where waste containers are received, inspected, and prepared for transfer to the disposal silo.

- **Inspection and control zone**, intended for verification of container integrity and compliance with acceptance criteria.
- **Monitoring and control systems**, which oversee handling operations, radiation protection parameters, and operational safety conditions.

The building also accommodates laboratory functions for basic radiological and physico-chemical measurements, supporting operational control and verification activities.

From a safety perspective, the technological building plays an important role in ensuring that only compliant waste packages are emplaced in the repository. However, it is not intended for waste processing or conditioning, but rather for controlled handling, inspection, and support operations within the overall disposal system.

2.2.3 Administrative building

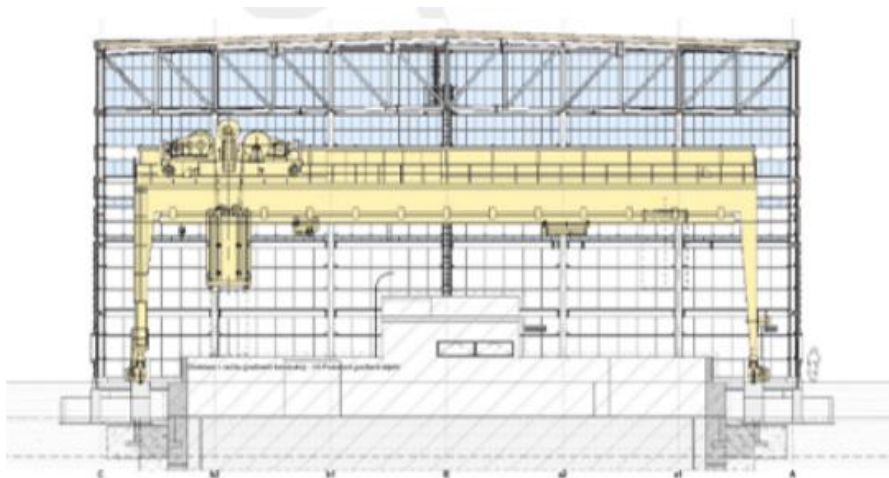
The facility is intended to support landfill management activities, along with associated service and administrative functions, access control operations, and the physical security of the disposal site. The building will also accommodate spaces designed for energy-related activities, fire water supply, municipal waste collection, storage of equipment and geological samples, as well as a workshop.

The structural design of the facility is aligned with the architectural concept and technological requirements. The building will be constructed on a stabilized gravel platform that was completed as part of preparatory works in 2017. The overall maximum plan dimensions of the facility are 13.85×89.65 m, with a maximum height of 8.52 m at the entrance section.

2.2.4 Hall above silo

Figure 5: Sketch of the hall above silo

During the operational phase of the disposal facility, a prefabricated steel hall will be constructed above the disposal silo to provide a controlled environment for waste handling and emplacement activities. The hall represents a key operational structure, ensuring safe and reliable execution of container transfer operations under varying environmental conditions.



The structure has approximate plan dimensions of 53.46×37.30 m, with a maximum height of approximately 18.4 m. It is designed as a steel frame construction with sufficient stiffness and load-bearing capacity to support the gantry crane system and associated operational loads. The hall

is anchored to the surrounding reinforced concrete structures to ensure overall stability and resistance to wind and seismic actions.

The primary function of the hall is to:

- protect the disposal silo and handling equipment from weather influences such as precipitation, wind, and temperature variations,
- provide a working environment for container handling and emplacement operations,
- enable safe and precise operation of the gantry crane system,
- ensure operational continuity and reduce downtime caused by adverse environmental conditions.

The hall accommodates the full operational envelope of the gantry crane, including horizontal movement along the crane runway and vertical lifting operations within the silo. The design also allows for the safe movement of transport vehicles delivering disposal containers, with dedicated access points located on both the northern and southern façades.

From a safety perspective, the hall contributes to operational safety by reducing external disturbances and enabling working conditions during lifting and emplacement activities. This is particularly important given the requirement for precise positioning of heavy disposal containers and the implementation of the Single Failure Proof (SFP) principle for lifting operations.

In addition, the enclosed structure supports radiation protection measures by providing a defined operational zone and enabling implementation of monitoring and access control systems. The hall thus represents an important interface between surface operations and the disposal system, ensuring that waste emplacement activities are carried out in a controlled, safe, and efficient manner.

2.3 Construction phase 3

In the third phase of the project, which represents the final stage of construction, the delivery, installation, and commissioning of the crane system and associated lifting equipment will be carried out. The system is designed to ensure safe, reliable, and precise handling of disposal containers during operational activities. The gantry crane will be operable both via a remote-control unit and remotely from the technological building using a camera-based control system, ensuring safe and efficient handling operations.

The system comprises a gantry crane with a main hoist designed for a rated critical load of 40 tonnes, supported by two auxiliary hoists. The first auxiliary hoist, with a capacity of 1.5 tonnes, is intended for the transfer of equipment into the silo or pumping station, as well as for personnel transport during inspection activities. The second auxiliary hoist, with a capacity of 3.2 tonnes, is dedicated to transport operations within the hall above the silo and on the working platform.

The main hoisting system is designed according to the SFP (Single Failure Proof) principle, ensuring a high level of operational safety. It is equipped with a specially designed mechanical gripping device featuring four rotating legs, which engage and secure the N2D container from below through a rotational locking mechanism.

The main hoist provides a lifting height of 58 m, while the auxiliary hoists reach lifting heights of 60 m and 7.6 m, respectively. The lifting speed of the main hoist ranges from 0.4 to 4 m/min, with trolley travel speeds between 0.5 and 5 m/min. The total length of the gantry crane runway is 52.8 m, with a span of 32 m.

TDelivery, commissioning, and final acceptance of the system are scheduled for completion by the end of 2027.

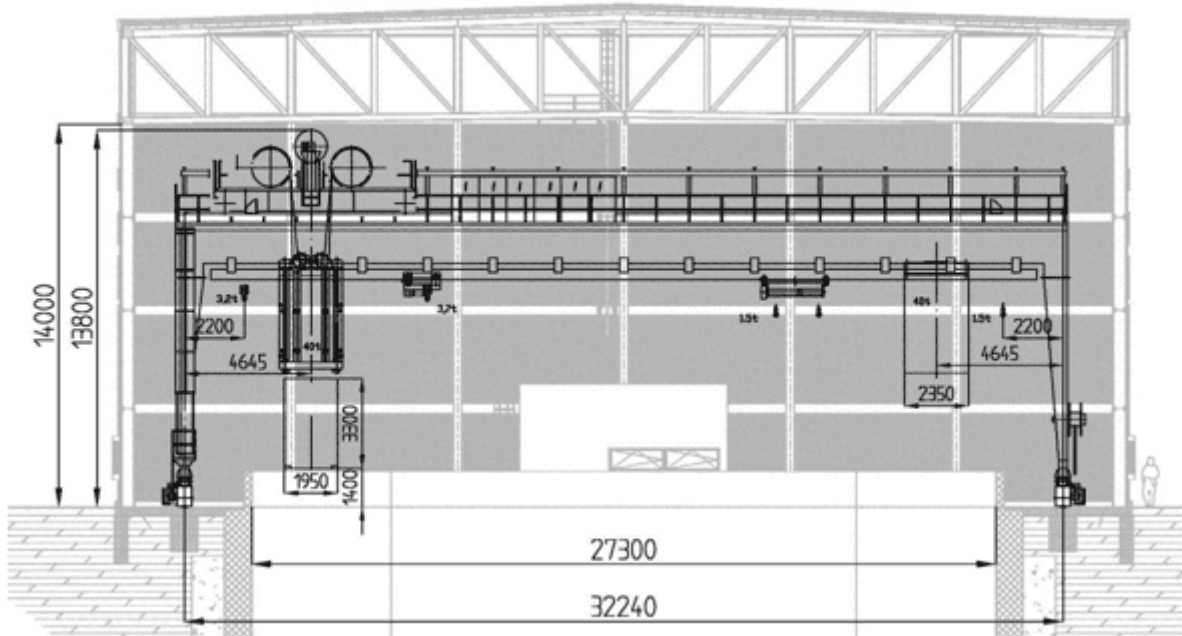


Figure 6: sketch of 40 t main lift

2.4 N2D disposal container

The N2D disposal container is designed to fulfil key safety and performance functions, including mechanical resistance, stability, durability, and long – term containment. As one of the

primary engineered components of the multi-barrier system, it plays a crucial role in preventing the release of radioactive substances from the repository into the environment.

The reinforced concrete container serves the following functions:

- Biological shielding during the pre-disposal phase,
- Mechanical protection of LILW during storage, handling and disposal,
- Safety function during transport and internal handling (transfer) of LILW within the facility,
- Standardized dimensional unit, governing waste packaging, conditioning, and disposal logistics,
- Primary handling unit for emplacement operations within the disposal silo.
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The N2d container for ILW storage has overall dimensions of 1.95 m × 1.95 m × 3.30 m, with variable wall thicknesses ranging from 20 to 23 cm. The basic geometry of the container was defined based on the arrangement of four TTC (tube type containers) drums. This design enhances both load-bearing capacity and operational flexibility during waste emplacement.

The N2D disposal container was developed in Slovenia as part of the national programme for the safe and long-term management of radioactive waste. The design reflects specific requirements of the Vrbinja disposal facility, ensuring compatibility with handling systems, disposal geometry, and safety functions within the multi-barrier concept.

All contractual arrangements for the manufacturing of the N2D containers have been completed. Currently, prototype containers are being fabricated and tested to verify compliance with design specifications and performance requirements. Serial production is planned to follow, with the first disposal containers expected to be available in 2027, in line with the planned commissioning of the repository.



Figure 7: Sketch of N2d container

3 DISPOSAL CONCEPT – HYBRID APPROACH

The Slovenian LILW disposal concept represents a hybrid approach that combines key features of both near-surface and geological disposal systems. Conceptually, it integrates elements of surface repository designs, as implemented in countries such as France and Spain, with features typical of underground disposal facilities, such as those in Sweden and Finland.

During the construction and operational phases, the facility functions as a near-surface disposal system, with waste emplacement carried out in engineered vertical silos accessible from the surface. This allows for efficient construction, operational flexibility, and direct control of disposal activities, similar to established near-surface repository concepts.

Following closure, however, the facility effectively transitions into a subsurface disposal system. The disposal silos, once sealed and covered, become an underground structure providing enhanced long-term isolation of radioactive waste from the biosphere. In this phase, the system relies primarily on passive safety functions, including engineered barriers and the surrounding geological environment.

This combined concept enables the integration of advantages from both disposal approaches, including:

- operational accessibility and flexibility during the active phase,
- robust engineered containment and long-term isolation after closure,
- effective implementation of the multi-barrier safety concept.

The facility uniquely transitions from a surface-operated system during its active phase to a passively safe subsurface repository after closure. By integrating engineered and natural barriers within a hybrid concept, the repository maximizes the safety advantages of both disposal approaches. The concept aligns with internationally established disposal practices while introducing an innovative combination of design features. The Vrbina facility represents a reference case for countries developing optimized disposal solutions for LILW. The design ensures that long-term safety is achieved primarily through passive systems, minimizing reliance on active control after closure.

The Vrbina disposal concept has been recognized as a technically robust and innovative solution, and is referenced as a successful example in international expert discussions and within the IAEA framework.

4 CONCLUSION

The development of the LILW disposal facility at Vrbina represents a key milestone in establishing a comprehensive and long-term solution for radioactive waste management in Slovenia. The project integrates advanced civil engineering practices with stringent nuclear safety requirements, ensuring compliance with both national regulations and relevant international standards for the safe disposal of low- and intermediate-level radioactive waste.

The phased construction approach has enabled a structured and controlled implementation of the repository, with Phase 1 successfully completed and Phase 2 progressing according to schedule. The execution of complex engineering works—such as the deep diaphragm wall, large-scale excavation, and construction of the multi-layered silo system—demonstrates the technical

robustness of the project. In parallel, the development of supporting infrastructure, including technological and administrative facilities, ensures full operational readiness of the site.

The final phase, involving the installation and commissioning of the gantry crane and lifting systems, will enable safe and efficient handling of disposal containers in accordance with the Single Failure Proof (SFP) safety principle. This represents a critical step in transitioning the facility from construction to operational status.

Overall, the Vrbinja repository embodies a modern multi-barrier disposal concept that combines engineered structures with natural geological protection. The project demonstrates that complex near-surface disposal facilities can be successfully implemented through the integration of conventional civil engineering solutions with nuclear safety requirements.

Upon completion, it will provide Slovenia with a safe, reliable, and sustainable solution for the long-term management of radioactive waste, thereby fulfilling both environmental responsibilities and intergenerational obligations. The experience gained during design and construction provides valuable insights for future disposal projects, particularly in the areas of deep excavation, engineered barrier implementation, and integration of safety requirements into large-scale infrastructure projects.

This case may serve as a reference model for similar LILW disposal facilities developed in comparable geological and regulatory environments.

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