



Application of ROM for Safe Decommissioning and Environmental Remediation of the Maišiagala RAW Storage Facility

CASE STUDY

KP-INPP-009

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Foreword

In 2021, the European Commission (EC) adopted a new proposal for a Council Regulation¹ 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 Regulation² 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 that facilitates the exchange of 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 multilateral knowledge transfers on decommissioning and waste management governance issues, managerial best practices, technological challenges, and decommissioning processes at both operational and organisational levels, as well as to develop potential EU synergies.

This is a knowledge product prepared by [Altra](#) for the 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)** presents the safe decommissioning and environmental remediation of the Maišiagala **radioactive waste (RAW)** storage facility, with a particular focus on the application of **remotely operated machinery (ROM)** during demolition, waste retrieval, dismantling and remediation activities conducted in **radiologically hazardous** and **confined environments**. Drawing upon final decommissioning reports, operational experience and supporting case materials, the KP documents how ROM was integrated with **radiological protection, contamination control, ventilation, monitoring, packaging** and **waste management systems** to enable safe and effective project delivery. It also captures **transferable technical, operational and organisational knowledge** that can support future decommissioning and remediation projects facing similar radiological, environmental and logistical challenges.

ABSTRACT

This KP presents a **practice-based case study** on the application of ROM during the decommissioning and environmental remediation of the Maišiagala RAW storage facility in Lithuania. The **project involved** the construction of the temporary infrastructure required for the removal of RAW, followed by the removal of contaminated structures and contaminated soil from a **legacy storage facility** characterised by **uncertain waste inventories, confined underground structures** and **significant radiological hazards**.

Particular emphasis has been placed on the deployment of a **BROKK 200** remotely operated machine to support demolition, excavation, waste retrieval and **handling activities** while **reducing direct worker exposure** to radiological hazards. The case demonstrates how ROM became effective not as a standalone technology but as part of an integrated operating system incorporating containment, ventilation, dust suppression, radiological monitoring, waste packaging, shielding arrangements and trained personnel.

The case study documents **practical lessons** associated with **remote demolition**, retrieval of **potentially hazardous contaminated sources (PHCS)**, management of unexpected conditions, operator competence development and the **integration of remote operations with waste management and regulatory requirements**. It also presents verified project outcomes, including complete removal of RAW from the storage facility, remediation of contaminated areas, transfer of **1,942 waste packages** to **Ignalina Nuclear Power Plant (INPP)** facilities and maintenance of worker doses well below regulatory limits.

The **principal transferable** message is that **successful deployment of ROM depends on the design of an integrated remote-work concept** rather than the selection of equipment alone. The documented experience provides practical implementation guidance for organisations undertaking decommissioning and remediation projects in hazardous, confined or poorly characterised environments and identifies opportunities for future enhancement through advanced robotic technologies, digital site characterisation and organisational knowledge reuse mechanisms.

OBJECTIVE

To record, convey and explain the knowledge gained during the application of ROM for safe decommissioning and environmental remediation of the Maišiagala RAW storage facility.

APPROACH

This KP was developed through referring to the following knowledge inputs as a contribution to the JRC's **Nuclear Decommissioning Knowledge Management (NDKM) Initiative**:

- final decommissioning and remediation reports of the Maišiagala RAW storage facility,
- results of radiological surveys, sampling and laboratory analyses,
- operational experience from waste retrieval, dismantling and environmental remediation activities,
- regulatory documentation, licences and approvals issued by the **State Nuclear Power Safety Inspectorate (VATESI)** and other authorities,
- practical application of remotely operated and robotic technologies (e.g. **BROKK-200**).

RESULTS, FINDINGS AND INSIGHTS

The Maišiagala project demonstrates that ROM can significantly reduce the need for direct human intervention in hazardous decommissioning environments while maintaining the capability to perform demanding demolition, retrieval and remediation tasks. The case confirms that successful outcomes were achieved through integration of ROM with containment systems, ventilation, dust suppression, radiological monitoring, shielding, packaging and trained personnel.

The project achieved complete retrieval and transfer of RAW from the storage facility, remediation of contaminated structures and soil, dismantling of temporary infrastructure following successful radiological surveys and substantial progress towards the intended end-state condition. A total of 1,570 m³ of waste (1,292.5 tonnes across 1,942 waste packages) was transferred to INPP's facilities. Collective worker dose for 2023-2024 was reported as 7.86 person-mSv and the maximum individual dose was 1.6 mSv. Although radiological release objectives were achieved, continued tritium monitoring remained necessary in part of the site.

The case further highlights several important insights for future projects, especially at legacy sites and facilities, including the importance of integrated system design, operator competence development, planning for uncertainty and unexpected discoveries, maintaining alignment between retrieval operations and downstream waste acceptance requirements and integrating remote technologies within broader project execution strategies. The experience also demonstrates that knowledge relating to practical remote operations is often experience-based and vulnerable to loss if not formally captured and transferred.

TARGET USERS

This KP is a valuable contribution to organisations involved in applying ROM at RAW storage facilities, as well as those with an interest in such activities and interdependencies with others across similar installations such as: decommissioning operators, contractors, regulatory bodies, academic and research facilities.

APPLICATION, VALUE AND USE

The information contained herein provides practical guidance for organisations involved in the decommissioning and environmental remediation of RAW facilities, [particularly where work must be undertaken in radiologically hazardous, confined, inaccessible or poorly characterised environments](#). This KP demonstrates how ROM can be planned, justified, deployed and integrated within wider decommissioning and remediation programmes while maintaining high standards of safety, environmental protection and operational control.

[Potential applications](#) include supporting the planning of remote demolition and waste retrieval campaigns, selection of appropriate remote operating strategies, integration of radiological monitoring and contamination control measures, preparation for unexpected radiological discoveries and development of operator training programmes. The documented experience may also support regulatory engagement, licensing discussions and demonstration of proven approaches for reducing occupational exposure during high-risk decommissioning activities.

[For decision-makers](#), the case study provides verified evidence of project outcomes, resource implications and operational considerations associated with remote technologies. [For practitioners](#), it offers practical lessons regarding equipment selection, work sequencing, waste retrieval, contingency planning and supporting infrastructure. [For organisations](#) seeking long-term capability development, this KP provides a transferable foundation for improving remote-work planning, technology adoption, knowledge retention and organisational readiness for future decommissioning projects.

KEYWORDS

Decommissioning, radioactive-waste management, remotely operated machinery, environmental remediation, radiation protection, remote demolition, waste retrieval, legacy facilities.

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ACRONYMS

ADR	European Agreement concerning the International Carriage of Dangerous Goods by Road
ALARA	As Low As Reasonably Achievable
EC	European Commission
EU	European Union
FDP	Final Decommissioning Plan
INPP	Ignalina Nuclear Power Plant
JRC	Joint Research Centre
KP	Knowledge Product
LL	Lesson Learnt
NDAP	Nuclear Decommissioning Assistance Programme
NDKM	Nuclear Decommissioning Knowledge Management
NDWM	Nuclear Decommissioning and Waste Management
NDWMD	Nuclear Decommissioning and Waste Management Directorate
NPP	Nuclear Power Plant
PHCS	Potentially Hazardous Contaminated Sources
R	Recommendation
RAW	Radioactive Waste
ROM	Remotely Operated Machinery
VATESI	State Nuclear Power Safety Inspectorate of Lithuania

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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), and full funding to the **EC's** internal NDWM programme, run by the JRC. This initiative is commonly known as the **Nuclear Decommissioning Assistance Programme (NDAP)**.

The same regulations mandated the **JRC** to initiate a knowledge management project on NDWM, based on the experience and lessons learnt during the implementation of the JRC's and NDAP Operators' decommissioning programmes. The primary products of the knowledge management project, referred to as KPs, will be disseminated to **European stakeholders** to support new operators entering NDWM activities, enabling them to benefit from knowledge gained through 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, specifically as an extension to what has already been provided by Altra under the initiative's ROM series³ based on their work at **Ignalina Nuclear Power Plant (INPP)**.

1.2. Overview of the case study



This KP represents a practice-based case study focused on ROM, based on the Maišiagala final decommissioning report and supporting case materials [9][10]. Prepared as a stand-alone KP for practitioners, decision-makers and knowledge management audiences.

Purpose: This document captures how ROM was used, why it mattered, what enabling conditions were necessary, what outcomes were verified and what other decommissioning projects can realistically reuse.

³ The other KPs developed under the NDWM Initiative's ROM series are encoded [KP-INPP-005](#) and [KP-INPP-007](#), both accessible at the time of writing on the KP database via the following link: [Search Knowledge for policy](#).

2. CASE STUDY



This KP is best framed as a strengthened case study with implementation advice. The central lesson from Maišiagala is not simply that a BROKK-200 robot was used but that ROM became effective when integrated with containment, ventilation, radiation monitoring, shielding, compatible packaging and a trained workforce.

Why the case matters

- Legacy site with unsegregated waste and uncertain subsurface conditions.
- Need to remove waste and contaminated structures while minimising worker exposure.
- Sensitive environmental and public context near protected areas. [5][9]

What makes the case reusable

- Clear workflow for remote demolition, excavation, retrieval and packaging.
- Verified project outcomes and dose indicators from the final report.
- Transferable lessons on enabling systems, training and logistics. [9][10]

The indicators presented in [Figure 2](#) demonstrate the scale of the campaign, the level of workforce preparation required and the radiological outcomes achieved, providing context for the role played by ROM within the broader decommissioning programme.

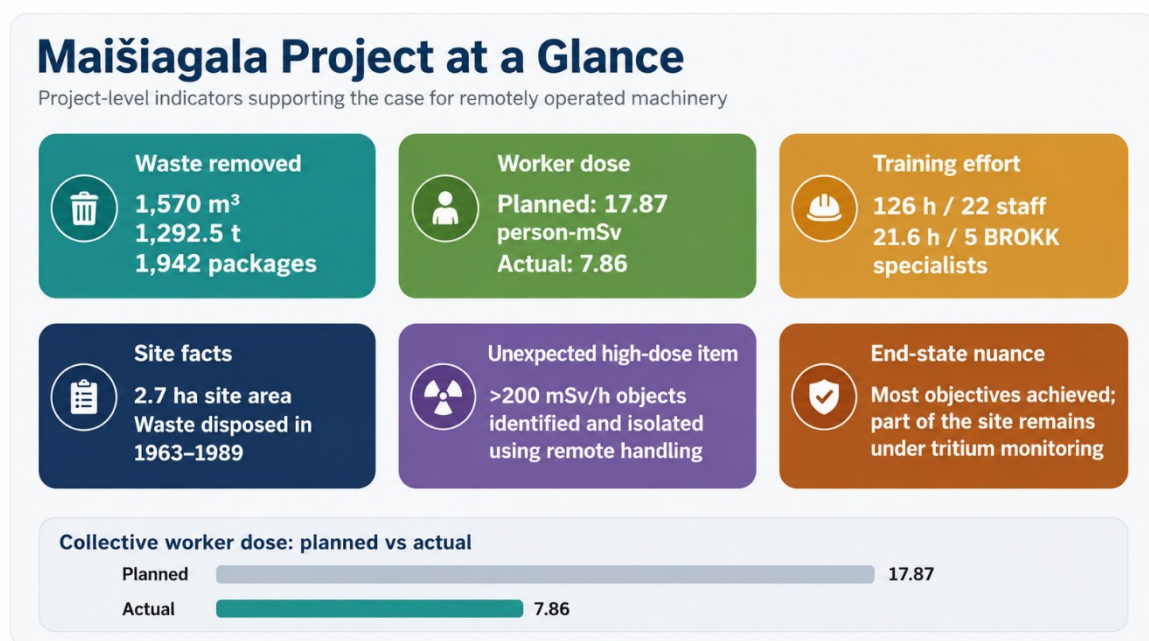


Figure 2. Selected project indicators compiled from the Maišiagala final decommissioning report and case materials

2.1. Strategic Context and Problem Definition

Maišiagala was a legacy RAW storage facility occupying approximately 2.7 ha. From 1963 to 1989, used sealed sources and RAW from industry, healthcare, research institutions and military units were disposed there without modern segregation and engineered isolation. Although new engineered barriers were installed in 2006, the site still did not provide adequate long-term isolation from the environment [4][5].

Key operational challenges

- Radiological risk from direct human presence
- Reinforced concrete and asphalt demolition
- Confined basement access and uncertain waste distribution
- Secondary contamination and airborne dust control
- Need for compatible transport, packaging and shielding



Figure 3. Maišiagala site before decommissioning works (adapted from the Final Decommissioning Report [9])

Therefore, the decommissioning objective was to remove all RAW, contaminated structures and contaminated soil, to remediate the site and to terminate radiological control to the maximum extent possible. This had to be done while reducing worker exposure and controlling contamination spread during demolition and retrieval. [Figure 3](#) above shows the site before decommissioning works and [Figure 4](#) shows a condensed timeline showing why the case is relevant beyond a single demolition activity.



A particular concern was the possibility of encountering PHCS, which further strengthened the case for remote intervention.

Project Timeline and Context

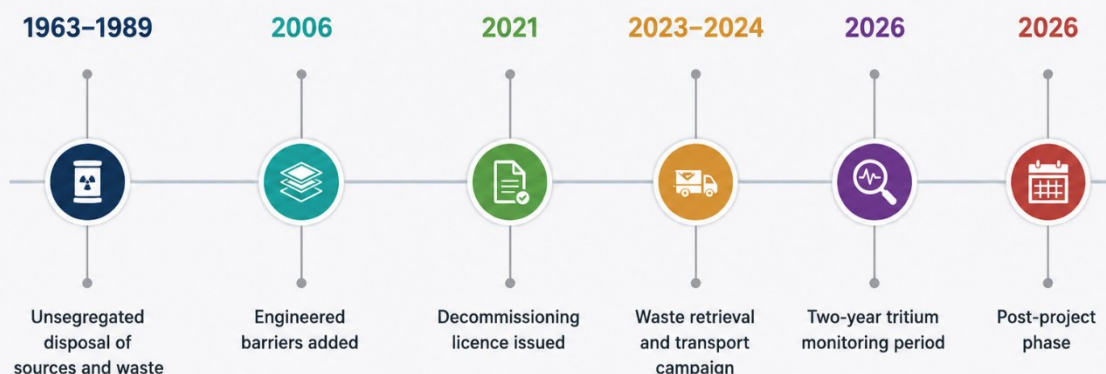


Figure 4. Condensed timeline showing why the case is relevant beyond a single demolition activity

2.2. Why Remotely Operated Machinery Was Needed



Conventional demolition with direct human presence would have been less attractive at Maišiagala because the work combined structural demolition, contaminated soil excavation, uncertain subsurface conditions and the possibility of encountering high-dose items embedded in structures or mixed with debris [4] [9].

Therefore, the selected approach relied on ROM to maintain a safe distance of people from the hazard while retaining sufficient demolition force and manoeuvrability.

Remote operation

Operators remained outside the highest-risk work area during demolition, retrieval and packaging support.

Compact power

BROKK 200 combined compact dimensions fitting within the vaults with enough power for concrete, asphalt, rebar and soil-related tasks.

Task flexibility

Interchangeable attachments allowed fast switching between breaking, grabbing, cutting, cleaning and excavation.

[Figure 5](#) illustrates an important systems-level lesson from Maišiagala. ROM reduced exposure risks but its effectiveness depended on integration with containment, ventilation, monitoring, waste management and operational controls.

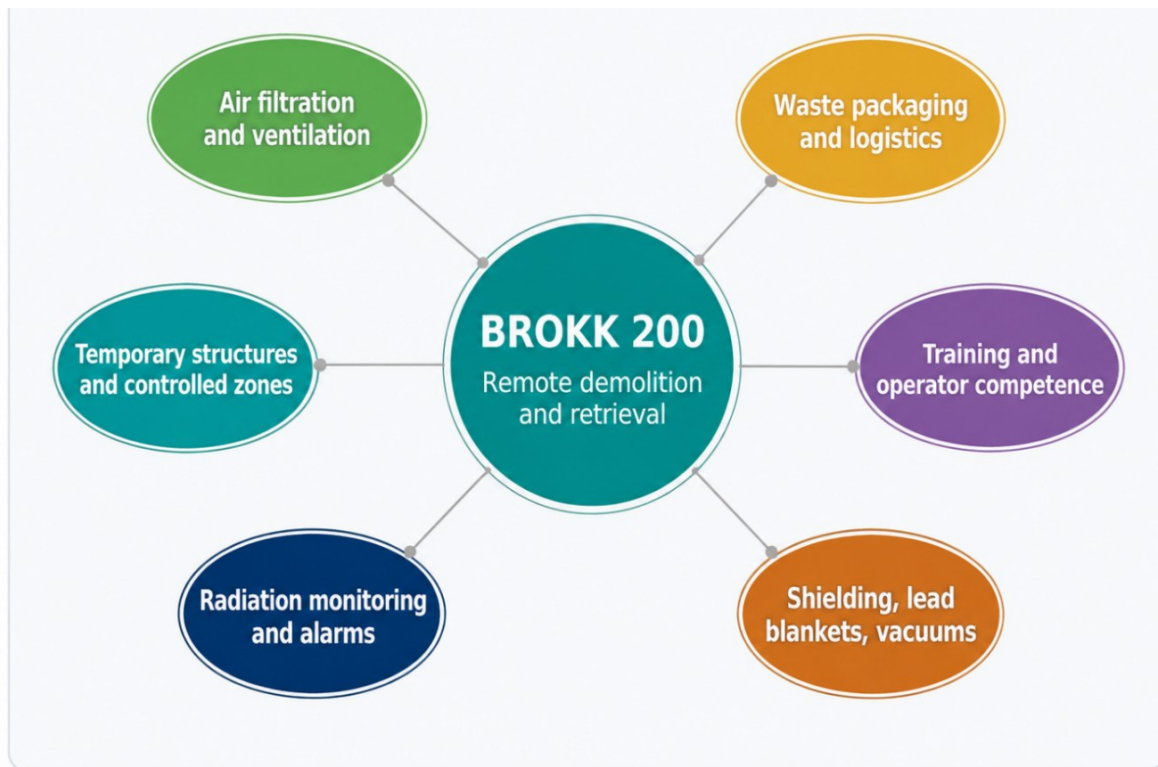


Figure 5. BROKK 200 in an integrated operating environment



Knowledge-transfer insight: The effectiveness of the BROKK 200 arose from the operating system surrounding it, not from the machine alone. Containment, ventilation, monitoring, shielding, packaging, logistics and operator competence collectively enabled remote working to deliver a safe project outcome.



Transferable lesson: Define the complete remote-work system before selecting the machine. Equipment requirements should be derived from the task sequence, radiological conditions, access constraints, supporting controls, waste route and credible recovery scenarios.

As discussed further in [subsection 2.6](#), successful deployment depended on a range of supporting systems beyond the ROM itself.

2.3. Operational Application at Maišiagala



At Maišiagala, ROM was used as a multifunctional platform for: (i) removing upper asphalt and concrete layers, (ii) opening access to the basement, (iii) excavating sand and contaminated soil, (iv) breaking and cleaning vault structures, (v) retrieving and sorting PHCS and (vi) supporting packaging and waste transfer.

The sequence below in [Figure 6](#) reconstructs the practical use of **BROKK 200** and associated systems used during demolition and retrieval activities, sourced from case materials and the final report. Operators, monitoring systems, ventilation, dust suppression, packaging and logistics worked as **one integrated chain**. This further demonstrates that operations were integrated with radiological protection, contamination control and waste handling activities.



Figure 6. Reconstructed operational workflow for ROM at Maišiagala



Knowledge-transfer insight: Remote operation changes the nature of human involvement rather than removing it. Safe and effective performance remained dependent on operators being able to interpret visual and radiological information, select suitable attachments and adapt the intervention sequence as field conditions evolved.

The field images below shown in the following figures ([Figure 8](#) to [Figure 10](#)) illustrate the working environment within which this combination of equipment, information and operator judgement was applied. This provides visual evidence of the controlled demolition, waste-retrieval and remediation campaign, including the ROM, primary containment and temporary supporting infrastructure used during the works. The progression to the post-decommissioning site condition is presented subsequently in [Figure 12](#) and [Figure 16](#).

Selected field images



Figure 8. Cold testing / start of remote demolition of the upper part of vault “r1”



Figure 7. Operation inside the primary containment during waste retrieval



Figure 9. Remote demolition and excavation inside the former liquid waste vault



Figure 10. Caisson / temporary structure context supporting safe retrieval and dismantling

2.4. PHCS Handling and the Value of Remote Intervention



One of the strongest knowledge elements in the source material is the use of ROM for localisation, retrieval and handling of PHCS. Video monitoring and radiometric detection allowed operators to identify suspicious items, assess their position and then choose an appropriate attachment or intervention sequence.

How the PHCS task was executed

- Locate items with video and radiometric aids.
- Use suitable attachments for direct retrieval or for careful breaking of surrounding concrete.
- Control radiation and maintain remote operation throughout the sequence.
- Place items into protected containers and coordinate packaging, shielding and subsequent logistics.

Interesting site-specific fact

During waste retrieval in room 103 of vault “r1”, two unidentified cylindrical radiation-emitting objects with dose rates exceeding 200 mSv/h were discovered and remotely placed into a K-190 type container. This is a specific example of the value of ROM in unexpected situations.



Knowledge-transfer insight: Successful remote retrieval did not by itself constitute a complete waste-management solution. The retrieved objects also had to be characterised, shielded, packaged and transferred through an approved downstream waste-management route.



Transferable lesson: Future projects should trace each anticipated waste stream from the point of retrieval to an accepted storage or disposal destination before finalising the remote-work sequence. Container availability, shielding needs, package acceptance limits and transport constraints should inform retrieval methods, attachment selection, segregation and workforce logistics.

This integration of remote retrieval with detection, shielding, packaging and downstream logistics contributed to the verified project outcomes summarised in [subsection 2.5](#).



Figure 11. Remote handling during retrieval operations

2.5. Verified Decommissioning and Remediation Outcomes



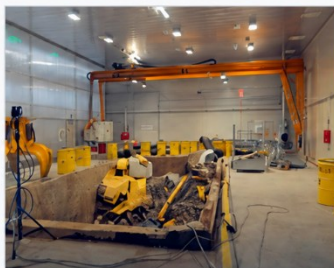
The final decommissioning report is particularly valuable because it moves the case from a generic technology narrative to a verified industrial application. It confirms that all RAW present in the storage was removed, preliminarily classified and transported to Ignalina NPP facilities.

In addition to waste retrieval and dismantling activities, contaminated soil was excavated and the site was remediated to support achievement of the project's intended end-state objectives. It was also recorded that temporary infrastructure was dismantled after final radiological surveys confirmed compliance for the relevant objects and areas [7] [9].

Before / During / After



Before decommissioning



Remote work campaign in a controlled enclosure



After decommissioning / site remediated

Figure 12. Visual progression from pre-project state to the controlled work campaign and the post-decommissioning site condition

Waste moved

1,570 m³ of waste / 1,292.5 t / 1,942 packages transferred to Ignalina NPP facilities.

Dose indicators

Actual collective worker dose in 2023–2024: 7.86 person-mSv; maximum individual dose: 1.6 mSv.

Training effort

Operator training programme: 126 h for 22 employees; BROKK-focused special training: 21.6 h for 5 employees.

End-state nuance

End-state objectives were achieved, but a part of the site still requires tritium monitoring before full green-field status can be considered.

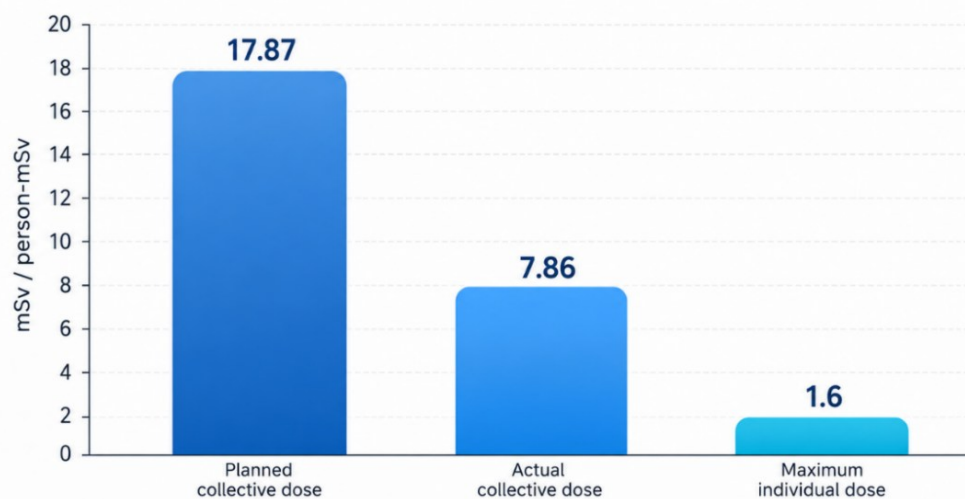


Figure 13. Selected dose indicators reported for the Maišiagala decommissioning project

2.6. Enabling Systems and Supporting Equipment



The report shows that the robot operated within a broader system of temporary infrastructure and supporting equipment. This is one of the most transferable insights from the case.

Deployment of ROM took place within an established regulatory framework governing radiological protection, waste management and decommissioning activities.

Table 1. Enabling systems and supporting equipment with respect to element, role and examples from the case

 Element	 Role in the operating chain	 Examples from the case
 Containment / infrastructure	Created controlled zones for retrieval and demolition	Caisson, primary enclosure, temporary buildings, fencing, utilities
 Ventilation and contamination control	Managed airborne contamination and working conditions	Air filtration, water spraying, vacuums / HEPA-based dust removal
 Radiation protection systems	Provided monitoring, alarms and data support	Radiation control system, dosimeters, gamma/beta/alpha/neutron monitoring
 Handling and logistics	Supported movement, loading, packaging and shielding	Gantry crane, rail trolley, forklift, lead blankets, approved containers

Temporary structures, containment systems, ventilation systems, radiation monitoring equipment, shielding arrangements and certified waste packages collectively formed the operating environment within which ROM could be used safely and effectively [4] [6] [9].



Figure 14. Temporary infrastructure installed to support safe waste retrieval and decommissioning operations

Regulatory and licensing framework

Deployment of ROM formed part of a wider licensed decommissioning and environmental remediation programme implemented under the oversight of the State Nuclear Power Safety Inspectorate (VATESI) and other Lithuanian authorities.

Key **regulatory milestones** included: completion of the **environmental impact assessment process** and the positive decision issued by the Environmental Protection Agency [5], approval of the **final decommissioning plan** [4] by the Lithuanian Minister of Energy following review by VATESI and the Ministry of Energy, issuance of the **VATESI decommissioning licence** [6], approval of the **supporting safety documentation** and authorisation of radioactive-waste transport activities [8].



Knowledge-transfer insight: The successful use of ROM depended on its incorporation into the licensed decommissioning strategy, rather than its treatment as a stand-alone equipment decision. This alignment connected the remote-work concept with radiological protection, ALARA, waste management and the regulatory controls governing demolition, retrieval and remediation.

2.7. Transferability, Limitations and Boundary Conditions



This case is highly useful internationally because it combines technical, radiological, logistical and organisational lessons. However, it should not be oversimplified. Project-level outcomes cannot be attributed to the robot alone and not every element is directly transferable without adaptation.

Although the **principal decommissioning objectives** were achieved, additional monitoring remained necessary to confirm **long-term environmental conditions** relating to residual tritium [7] [9].

Transferability: What Others Can Reuse

Directly transferable

Remote operation for hazardous demolition; staged excavation; integrated dust suppression; real-time monitoring; waste packaging discipline.

Transferable with adaptation

PHCS retrieval logic; basement access approach; use of interchangeable tooling; handling of unexpected high-dose items.

Site-specific elements

Geometry of reservoirs, waste composition, radiological distribution, soil behaviour, local logistics and package routes.

Critical preconditions

Licensing, trained operators, containment and ventilation, supporting equipment, compatible containers, RP procedures and data-driven decision making.

Figure 15. Practical view of what others can reuse directly and what must be adapted to local conditions.

The implications of these boundary conditions are reflected in the lessons learnt and recommendations presented in [subsections 3.1](#) and [3.2](#), respectively.

Limitations and cautions

- It is not claimed that ROM alone delivered the project outcome; success depended on the full system around it.
- Electronics tolerance and maintenance needs may constrain use in some environments [10].
- Transport compliance and packaging certification remain critical even when retrieval is technically successful [8] [9].
- Part of the Maišiagala site still requires tritium monitoring after decommissioning [7] [9].

Implementation advice for future users

- Map the task sequence before selecting tools and attachments.
- Plan for radiation-resistant equipment, components and materials where required.
- Link remote work planning with radiation protection, packaging and logistics from the start.
- Train operators as a dedicated competence, not as an afterthought.
- Prepare decision rules for unexpected high-dose items and unstable excavation geometry.

Environmental protection measures were integrated throughout retrieval and remediation activities. These included:

- construction of secondary containment structures above the repository vaults,
- installation of negative-pressure ventilation systems equipped with high-efficiency particulate air filtration,
- radiological monitoring of personnel and work areas,
- contamination control arrangements,
- ongoing environmental surveillance [4–7,9].



Knowledge-transfer insight: ROM reduced the need for direct worker presence in elevated-radiological-hazard areas but the exposure benefit depended on its use alongside containment, ventilation, contamination control and radiological monitoring.



Transferable lesson: Future projects should assess ROM as one element of a layered protection strategy. Remote operation should be planned together with containment, ventilation, monitoring, maintenance access and recovery arrangements, rather than credited as an independent exposure-control measure.

3. KEY TAKEAWAYS

Maišiagala demonstrates that ROM can make a decisive contribution to safe decommissioning and environmental remediation when it is embedded in a disciplined operating system. Therefore, the strongest transferable message is not merely “use a robot” but “design an integrated remote-work concept” that aligns demolition, excavation, radiological protection, contamination control, packaging, logistics, competence and regulatory interfaces.

For organisations seeking to reuse this experience, the value of this KP lies in three things: a practical workflow, verified project evidence and an honest account of the boundary conditions that made the approach effective.



Figure 16. Site condition after decommissioning works (cropped from the final report appendix).

Result

The project removed the radioactive-waste inventory, contaminated structures and affected soils, as well as dismantled the former storage facility. Relevant structures and surface areas met the applicable radiological release criteria, although continued monitoring remained necessary for residual tritium in part of the site.



Knowledge-transfer insight: Successful retrieval and physical remediation do not necessarily produce immediate unrestricted release of the entire site. Residual environmental pathways may require monitoring after the principal dismantling and remediation work has been completed.



Transferable lesson: Future projects should define the decommissioning end state and the post-remediation monitoring state separately. Plans, budgets and stakeholder communications should allow for residual monitoring where complete release cannot be demonstrated when physical works finish.

3.1. Lessons Learnt

Six (6) lessons learnt (LLs) from **Altra's** experience of applying ROM for safe decommissioning and environmental remediation are recorded in this subsection.



#LL-1. Integration Matters More Than Individual Technology

Maišiagala demonstrates that project outcomes cannot be attributed solely to the BROKK 200. Success resulted from integration between ROM, containment systems, ventilation, dust suppression, radiation protection, waste packaging, monitoring arrangements and trained personnel. Future projects should view ROM as one component of a broader operational system rather than a standalone solution.



#LL-2. Flexible Equipment Reduces Operational Interruptions

The ability to switch rapidly between demolition, excavation, retrieval and cleaning tasks using interchangeable attachments reduced operational complexity and improved adaptability to evolving field conditions.



#LL-3. Human Capability Remains Critical in Remote Operations

Remote operation reduced direct exposure but project success remained highly dependent on workforce competence, training quality and the ability of operators to interpret radiological and visual information effectively. Therefore, training should be viewed as a primary project requirement rather than a support activity.



#LL-4. Retrieval Success Does Not Eliminate Downstream Constraints

The case study highlights that retrieval and dismantling activities must remain aligned with transport arrangements, approved containers, shielding provisions and waste acceptance requirements. Operational success can otherwise become disconnected from disposal or storage pathways.



#LL-5. Plan for Unexpected Conditions from the Outset

Legacy RAW facilities often contain uncertainties relating to waste inventories, source locations, structural conditions and radiological characteristics. At Maišiagala, the discovery of previously unidentified radiation-emitting objects during retrieval activities demonstrated the importance of maintaining flexible operating strategies, appropriate monitoring arrangements and predefined response procedures. Future projects should assume that unexpected conditions may be encountered and incorporate sufficient technical, logistical and decision-making flexibility into project planning and execution.



#LL-6. Brownfield Monitoring Legacy

A notable lesson from the project is that successful remediation does not always result in immediate unrestricted site release. Although remediation objectives and clearance criteria were achieved, continued monitoring of residual tritium concentrations in groundwater remains necessary. This demonstrates the importance of incorporating long-term environmental monitoring and post-remediation land-use considerations into decommissioning planning from the earliest project stages.

3.2. Recommendations

Six (6) recommendations (Rs), based on **Altra's** experience of applying ROM for safe decommissioning and environmental remediation, have been provided below with a view of informing similar future works.



#R-1. Plan Remote Operations as an Integrated System

Future projects should develop integrated remote-work strategies during planning stages, ensuring that demolition, excavation, radiation protection, contamination control, packaging, monitoring and logistics are addressed collectively rather than independently.



#R-2. Invest Early in Operator Competence Development

Structured training programmes should begin before radiological work commences and include simulated operating conditions, emergency scenarios and attachment-change procedures.



#R-3. Develop Response Strategies for Unknown High-Dose Objects

Projects involving legacy waste inventories should establish predefined decision-making and retrieval procedures for unexpected radiological discoveries, including equipment requirements, monitoring actions and container availability.



#R-4. Improve Digital Site Characterisation and Operational Awareness

To support demolition-sequence planning and progress monitoring, future projects should investigate the enhanced integration of three-dimensional site modelling, digital twins, photogrammetry, light detection and ranging surveys as well as remote radiation mapping.



#R-5. Investigate Advanced Robotic and Sensor Technologies

Future projects could, where radiological and regulatory conditions permit, evaluate: semi-autonomous robotic functions, machine vision-assisted object recognition, robotic manipulators, remote radiation imaging and unmanned aerial systems for inspection.



#R-6. Establish Organisational Knowledge Reuse Mechanisms

Organisations operating ROM programmes should consider developing: a ROM lessons-learnt repository, reusable remote-work planning guidance, case-study libraries, equipment selection matrices and training modules derived from previous deployments.

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