Information System Modernization for Safe and Traceable Management of Radioactive Waste at ARAO

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ABSTRACT

In 2024, ARAO initiated a comprehensive modernization of the information system supporting the management of radioactive waste. The legacy application, originally developed in 2007 to support waste acceptance, treatment, conditioning and storage at the Central Storage Facility (CSF), had become technologically outdated and insufficient to support new operational and regulatory requirements, particularly those associated with the forthcoming operation of the Low- and Intermediate-Level Radioactive Waste Disposal Facility. The project was procured as a turnkey solution through a public tender procedure and is being implemented in clearly defined phases, covering system design, redevelopment of the CSF module, migration of historical operational data, and development of a new module dedicated to disposal operations.

The new application preserves the existing waste management workflows while introducing enhanced traceability, structured data validation, role-based access control, and comprehensive audit trails, in line with nuclear safety and information-security requirements. Attention is given to maintaining continuity of regulatory reporting, documentation generation, and long-term inventory tracking across the transition from storage to disposal. The functional design explicitly integrates the operational logic of waste acceptance, package verification, inventory management, and administrative control, while establishing a digital framework for the future disposal process at Low- and Intermediate-Level Radioactive Waste Disposal Facility.

A key driver of the modernization was the transition from a storage-only system supporting a single facility to a lifecycle-oriented system integrating storage and disposal operations and accommodating both institutional radioactive waste and waste from the national nuclear power plant.

The paper presents the project objectives, procurement and implementation approach, and early operational experience. Special emphasis is placed on the migration of historical waste data from the legacy system, which proved to be less complex than initially anticipated, and on practical lessons learned when introducing a new digital system into a safety-critical radioactive-waste management environment. The project represents a key step towards ensuring long-term data integrity, operational transparency and regulatory compliance throughout the full lifecycle of radioactive waste management in Slovenia.

Keywords: *radioactive waste management, waste traceability, regulatory compliance, data migration*

1 INTRODUCTION

Radioactive waste management represents a key component of nuclear safety, where reliable and long-term data management plays a critical role. Information systems in this context are not

merely supporting tools but essential elements of safety infrastructure, enabling control of material flows, providing traceability, supporting regulatory compliance, and facilitating decision-making.

The International Atomic Energy Agency (IAEA) emphasizes that traceability of radioactive waste must be ensured throughout its entire lifecycle, over timescales potentially spanning several generations [1]. Similarly, the OECD Nuclear Energy Agency (OECD/NEA) highlights the importance of digitalization in improving process integration, transparency, and long-term knowledge preservation [2].

In advanced national programmes information systems support comprehensive data management across all stages, from waste generation to disposal and long-term monitoring.

At ARAO, an information system supporting radioactive waste management processes was introduced in 2007. While it significantly improved operational efficiency and traceability at the time, it was primarily designed for storage operations. The transition towards disposal required a fundamental modernization of the system.

Until now, ARAO has been responsible primarily for the management of institutional radioactive waste, which is collected, processed and stored at the CSF. This storage facility has been the only operational facility under ARAO's direct management, and the existing information system was therefore designed exclusively to support storage-related processes.

The situation is now changing with the construction of the national Low- and Intermediate-Level Radioactive Waste Disposal Facility. This facility will receive waste from two distinct sources: institutional waste currently stored at CSF and operational waste generated by the Krško Nuclear Power Plant.

This transition introduces a significant increase in system complexity, as it requires integration of institutional radioactive waste with waste from the national nuclear power plant, while extending data management from storage-only to full lifecycle coverage, including disposal.

This paper presents the modernization approach, system design, and implementation experience, with particular emphasis on data migration and the transition to lifecycle-oriented waste management.

2 INTERNATIONAL CONTEXT AND ROLE OF INFORMATION SYSTEMS

Modern radioactive waste management relies on several key pillars, including safety, regulatory compliance, long-term data preservation, and information security.

IAEA safety standards emphasize the importance of maintaining comprehensive records that remain accessible, interpretable, and reliable over long time periods [1]. OECD/NEA further stresses the need for preserving knowledge and providing continuity of information across generations [2].

In this context, modern information systems are increasingly designed as lifecycle-oriented data management systems that integrate multiple operational stages and support long-term knowledge preservation and regulatory verification. Such systems enable consistent linking of data across different phases of radioactive waste management while ensuring that information remains accessible, interpretable, and verifiable over extended timescales.

These systems play a crucial role in ensuring that data remain consistent and usable over the entire lifecycle of radioactive waste.

3 LEGACY INFORMATION SYSTEM AT ARAO

The legacy system, introduced in 2007, supported key processes such as waste acceptance, processing, conditioning, and storage. The central element of traceability was the waste package, which was uniquely identified and tracked across all process stages. The solution was deployed as a locally installed desktop application, operating on individual user workstations, which limited central control, data consistency, and traceability of user actions.

The solution enabled centralized data entry, automated document generation, and regulatory reporting, significantly improving operational transparency.

Technically, the system was based on a three-tier architecture, separating presentation, application logic, and data layers, following service-oriented design principles.

Despite its robustness, several limitations became evident over time:

- technological obsolescence,
- limited adaptability to new processes,
- dependence on outdated development support,
- lack of flexibility for integration of disposal processes.

These limitations became critical in the context of future disposal activities.

4 DRIVERS FOR MODERNIZATION

The modernization was driven by a combination of technical, regulatory, and strategic factors.

From a technical perspective, maintaining and upgrading the legacy system became increasingly difficult due to outdated technologies and lack of development support.

From a regulatory perspective, requirements for traceability, transparency, and long-term data preservation have become more stringent, requiring improved data integrity and auditability [1], [2].

The key strategic driver was the transition from storage to disposal. While the legacy system was focused on storage, future operations require full lifecycle management, including disposal preparation and long-term monitoring.

These combined factors made modernization essential for ensuring continued safe, reliable, and compliant operation.

In the previous operational model, the information system supported a single facility with well-defined processes. The introduction of the disposal facility fundamentally changes this paradigm, as it requires coordination between multiple facilities and integration of different waste streams with distinct regulatory and operational characteristics.

5 MODERNIZATION APPROACH AND PROCUREMENT STRATEGY

In the initial phase of the project, ARAO evaluated existing commercial solutions available on the international market. While these systems offer advanced functionality and benefit from continuous development, they are often designed for broader applications and may require adaptation of local processes.

Given the specific nature of national radioactive waste management, ARAO decided to develop a custom system that builds on the established business logic of the existing application while allowing full adaptation to local requirements. This approach reflects a common balance between standardization and customization in specialized information systems.

The project was implemented as a turnkey solution through a public procurement procedure, providing transparency, compliance with legal requirements, and selection of a technically and economically suitable provider.

6 SYSTEM DESIGN

6.1 Architecture and Security

In contrast to the legacy system, the new solution is implemented as a centralized web-based application, providing a single point of data access and control across all users.

This approach represents a significant shift from the previously distributed desktop-based architecture, where the application was installed locally on individual user workstations.

It is based on a modular architecture that separates key functional domains while allowing controlled interaction between them.

The system operates in a strictly controlled offline environment without direct internet connectivity, which significantly reduces exposure to external threats but also introduces additional complexity in data exchange and system maintenance.

To address information security requirements, the system incorporates multiple layers of protection. Access is controlled through role-based mechanisms integrated with centralized identity management, while authentication relies on multi-factor verification. In addition, all user actions are recorded, providing full traceability of activities. These measures are aligned with recognized practices for computer security in nuclear facilities [3].

6.2 Design Principles and Data Model

A central objective of the system design was to ensure that the identity and history of each waste package are preserved throughout its entire lifecycle. This requirement has influenced both the data model and the structure of operational workflows.

The solution is based on the principle that all relevant data are maintained within a single, consistent structure, avoiding duplication and inconsistencies. Once key process steps are completed, data are effectively locked, preventing unintended modifications and ensuring the integrity of historical records. At the same time, all changes made during earlier stages are recorded in detail, including the identity of the user and the time of the modification, which allows full reconstruction of the data history.

Operational processes are implemented as controlled workflows, where transitions between stages are only possible after validation of required conditions. In irreversible process steps, confirmation by two independent users is required, reducing the likelihood of errors.

At the core of the system is the waste package, which serves as the primary entity linking all relevant information, including physical properties, radionuclide composition, processing history, and storage location. This approach enables consistent tracking of each package across all operational phases and provides a solid foundation for future integration of disposal processes.

7 IMPLEMENTATION AND SYSTEM INTEGRATION

7.1 Data Migration

One of the most demanding aspects of the project was the migration of historical data from the legacy system. The migration covered approximately 25 years of operational data, including the entire inventory of radioactive waste stored at the Central Storage Facility.

The process involved transferring all records related to waste packages, including their attributes, history of processing and movement, and associated documentation. Particular attention was given to preserving the identity of each package and maintaining consistency between related data.

Despite initial expectations, the migration process proved less complex than anticipated. This was largely due to the relatively consistent structure of the legacy data model. Data validation was performed through systematic comparison of records, verification of key parameters, and checks of traceability across different process stages.

The successful completion of the migration enabled the legacy system to be fully decommissioned, with the new system becoming the single authoritative source of data.

7.2 Operational Workflow

The solution supports the complete workflow of radioactive waste management, from the initial request for waste acceptance to the final administrative closure of the process. Each step is implemented as part of a structured sequence that ensures consistency and traceability.

The process begins with the submission of a request for waste transfer, followed by preparation of the necessary documentation. Once the waste is received, the data are verified, and any discrepancies are recorded and resolved. Verification is performed in two steps, requiring confirmation by independent users.

After successful verification, the waste packages are assigned to specific locations within the storage facility, where they are further monitored throughout their lifecycle. The process continues with financial and administrative steps, including billing and the issuance of a statement transferring responsibility for the waste.

Such structured implementation ensures that all relevant information is captured, validated, and preserved, while preventing incomplete or inconsistent process execution.

7.3 Disposal Module Development

The development of the disposal module presented a particular challenge, as the corresponding operational processes are not yet fully defined. This required a design approach that allows for future modifications without compromising existing data.

To address this, the system was developed with a flexible data structure capable of accommodating additional requirements as they emerge. In this way, the system not only supports current operations but also establishes a digital foundation for future disposal activities.

In addition to the lack of fully defined processes, the disposal module must also accommodate the integration of waste from different origins, including institutional radioactive waste and waste from the national nuclear power plant. This further increases the complexity of data structures and traceability requirements.

8 RESULTS AND LESSONS LEARNED

The implementation of the new system has resulted in a significant improvement in the management of radioactive waste data. All historical records are now consolidated within a single system, eliminating the need for parallel use of legacy tools and improving consistency of information.

It is important to note that the legacy system already provided a solid foundation for radioactive waste management, particularly in terms of traceability, as it ensured consistent tracking of waste packages throughout storage operations. However, it lacked full auditability of data changes and was built on outdated technology, which limited further development. The modernization therefore did not represent a complete redesign of operational logic, but rather a technological upgrade combined with targeted functional improvements and extension of the system to support new processes.

The introduction of structured validation, controlled workflows, and comprehensive audit trails has significantly improved the reliability and transparency of data. In particular, the ability to track all modifications, including user actions and timestamps, represents an important enhancement compared to the previous system. Improved reporting capabilities further enhance compliance with regulatory requirements while enabling more efficient preparation of documentation and data analysis.

Several important lessons were identified during the project. It was confirmed that preserving existing business logic is essential for ensuring a smooth transition, as it reduces the need for changes in established operational practices. At the same time, it became clear that data represent the most valuable component of the solution, as they must remain reliable over long periods, even as software solutions are updated and replaced.

The project also highlighted the importance of usability, as complex systems can introduce new risks if they are not sufficiently user-friendly. In addition, the need for flexibility was emphasized, particularly in relation to processes that are not yet fully defined, such as disposal operations.

At the current stage, the disposal module represents an initial operational version that is being used in a controlled test environment. The system is actively employed for simulated waste acceptance scenarios, enabling the identification of functional limitations and opportunities for improvement. In this phase, the module serves as a learning platform for validating operational workflows and boundary conditions. Based on these findings, further development will continue iteratively.

Despite these positive outcomes, several challenges remain. The use of a custom-developed solution requires a long-term strategy for maintenance and further development. The isolation of the system limits integration with other tools, and the disposal module will require further refinement once operational experience becomes available.

In addition, it is already anticipated that the application will require periodic renewal approximately every ten years, even in the absence of significant process changes, primarily due to rapid technological evolution. This introduces an additional long-term challenge related to the preservation of data, particularly in the context of facility closure. Ensuring that data remains accessible, interpretable, and usable over extended timescales will require careful consideration of data formats, migration strategies, and long-term storage solutions.

9 CONCLUSION

The modernization of the information system at ARAO represents an important step towards lifecycle-oriented radioactive waste management. The system provides a robust framework for providing traceability, data integrity, and regulatory compliance across all operational stages.

By integrating storage and future disposal processes within a single system, the solution establishes a foundation for long-term management of radioactive waste. The results demonstrate that information systems are not merely supporting tools but essential components of nuclear safety infrastructure.

The experience gained in this project may also be relevant for other small national programmes facing similar transitions from storage-focused systems to lifecycle-oriented radioactive waste management.

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