OPTMISATION; DOMAIN INSIGHT

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OVERVIEW

Many industrial and medical applications are generating radioactive waste (RW). This includes the operation of nuclear installations, the production, transport and use of radioactive material, the operation of hospitals, the chemical, oil and gas industries, etc. These wastes can be classified in different categories depending on the half-life (in years) and the level of radioactivity (in Bq). This includes very low-level activity (6-100 Bq/g) to high-level activity wastes that exceed 10^8 Bq/g (IAEA, 2009). Optimisation requirements implies that, when managing radioactive waste, the operators need to ensure that the radiological impacts on people and environment are kept as low as reasonably achievable. The issue of optimising predisposal waste management is complex and largely unexplored (in a holistic context); in particular at a national or international level (Nuclear Energy Agency, 2021). Due to various country-specific technical and non-technical factors, it is difficult to propose a universal solution for optimal predisposal waste management. Avenues for progress include the creation of a consistent terminology around optimisation of predisposal waste management for better communication among stakeholders, considering the incorporation of guidance on sustainability, optimisation, non-radiological risks and the “holistic approach” into all work programmes considering coordination and cost sharing of future international projects. Considerations to be taken in account to develop optimisation of a waste management program are the safety, economics, and other key objectives, national policy (responsibilities and funding), types and quantities of wastes (characterisation of waste streams, radiological, chemical, biological), treatment and disposal pathways, etc.

This Domain Insight “optimisation” is exclusively dedicated to optimisation of predisposal RW management activities. Predisposal covers all steps in the management of RW from its generation up to (not including) its disposal, which includes waste characterisation, processing (pre-treatment, treatment and conditioning), interim storage and transport. Details on all these steps can be found in separate DIs: Inventory (2.1.1), Waste Acceptance Criteria (2.1.2), Waste Hierarchy (2.1.4), Characterisation (2.1.2), Treatment & Processing (2.2.2), Conditioning (2.2.3), Transport (2.2.4), Storage (2.2.5), and Technology Selection (2.1.3).

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KEYWORDS

Optimisation, radionuclides, waste management, predisposal

KEY ACRONYMS

RNs – radionuclides
R&D – Research and Development
RW – Radioactive Waste
RWM – Radioactive Waste Management
DI – Domain Insight
BATs – Best Available Techniques
ALARA – As Low As Reasonable Achievable

1 TYPICAL OVERALL GOALS AND ACTIVITIES IN THE DOMAIN OF OPTIMISATION

There is no universal definition of “optimisation”, which may mean different things to people. Hence, a regulator may interpret the optimisation in terms of radiation protection including human and environment, while a facility operator may interpret it in the context of safety and cost-effectiveness. Nevertheless, in a quite general manner, “optimisation” can be defined as the process whereby an operator selects and implements the management option and the practices applied that best fulfil the requirement with regards health, safety, environmental and security (including safeguards) while taking into account the social and economic considerations. This involves the use of innovation with the best available techniques (BATs) that include the nuclear plant and the associated processes.

Optimisation of the nuclear cycle considers the goals in terms of minimisation of the environmental footprint, safety with a cost effectiveness manner (Figure 1). The same is to consider for decommissioning and remediation activities as well as final disposal of radioactive waste.

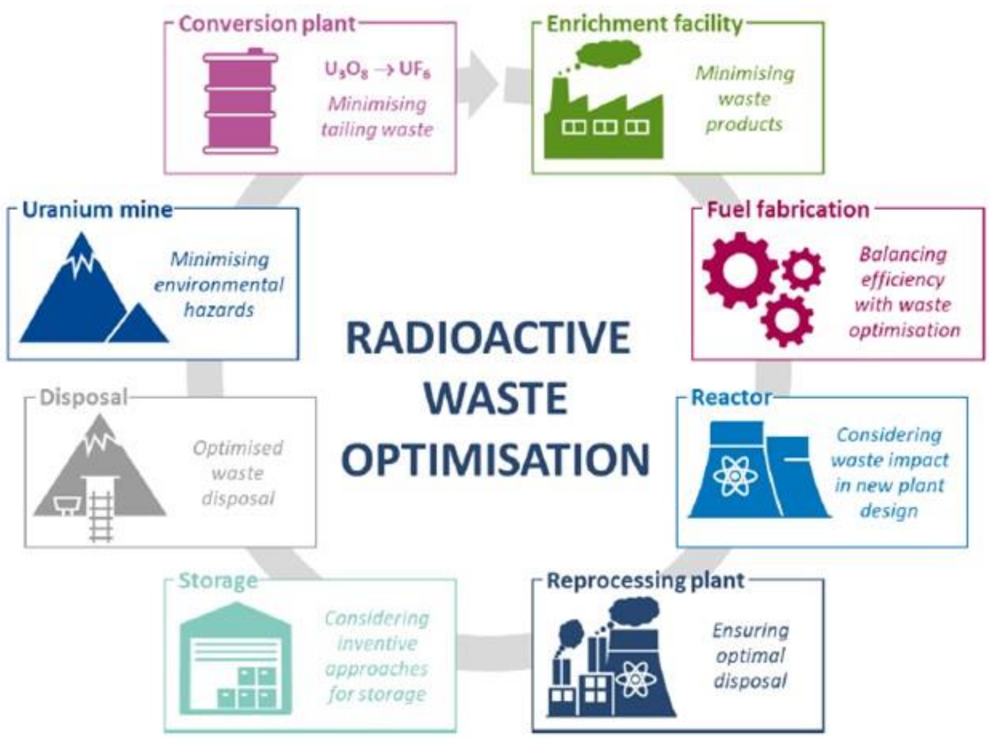

Figure 1 - Optimisation considerations for radioactive waste management according to Nuclear Energy Agency (2021).

Domain Goal	
2.3.2 Evaluate potential for improving and optimising implementation phases with new technologies, to improve costs and environmental impact while maintaining safety and accounting for potential risk scenarios (Optimisation)	
Domain Activities	
Phase 1: Planning and Programme Initiation	Understand national RWM policy (financial and legal issues). Definition of the waste process route for any specific waste stream and estimation of products and secondary waste arising. Compare processing technology options with respect to safety, economic and environmental life cycle parameters. Evaluate the interdependencies between the different predisposal processing steps (treatment, conditioning, storage). Understand regulatory requirements and prepare documentation for processing facility operation licensing.

Phase 2: Program Implementation	Maintain detailed records of waste history, inventory and processing (treatment, conditioning).
Phases 3-4: Program Operation/Optimisation and Closure	Manage iterative reviews and updates of processing plans and methods. Responding to latest technological development. Selection of the BAT. Responding to regulatory and waste acceptance requirements update.

2 INTERNATIONAL LEGISLATION

There are no international legislations strictly related to the radioactive waste optimisation domain. A number of binding and non-bonding international instruments are applicable to radioactive materials and spent fuel management. They are under the auspices of the IAEA, the NEA, the EU and the United Nations Economic Commission for Europe. In general, with the Directive 2011/70/Euratom, the EU establishes requirements for safe long-term management of radioactive waste. This encourages EU Member States to plan their waste management and spent fuel management programmes in a holistic manner.

3 GENERIC SAFETY ISSUES FOR OPTIMISATION

The safety issues for optimisation are basically associated with radioactive arisings at the three stages of the program (planning, implementation, operation/closure). Understanding the potential impact of radioactive waste on the safety of people and environment should be considered as one of the main drivers to conduct optimisation process. Optimisation will need to take place within a comprehensive safety framework that takes account of the legal framework, sustainability and cost drivers. The outcome of the optimisation should demonstrate a balance between dose impacts, waste volume, socio-economic implications and costs. Optimisation should be undertaken on an iterative basis to take account of learning and knowledge gained from site operations, industry best practice and stakeholder involvement.

3.1 Planning and Program Initiation

The principles for environmental optimisation of radioactive waste management rely on the use of the best available techniques (BAT) following a clear methodology such as described by the UK Environmental Agency, which are valid for all other countries. Optimization is indeed valuable from the planning and program initiation stage, given that technologies are evolving to address strict and new legislative requirements, which are intending to improve the human an environmental protection.

The BAT can be defined as the *latest stage of development (state of the art), of processes, of facilities or of methods of operation, which indicate the practical suitability of particular measure for limiting discharges, emissions and waste*.

Hence, according to the UK Radioactive substances management: generic developed principles (RDMDP4) states that "*The best available techniques should be identified by a methodology that is timely, transparent, inclusive, based on good quality data, and properly documented*".

Personnel competent in the matter of interest should carry out the process of identification of BAT, where the optimisation should lead to environmental benefits. The process of identification of BAT should:

- be initiated, when important information becomes known, for new sites during the design phase or in existing sites or facilities when modifications are envisaged.
- be transparent: fully documented and easy to review, the decision to be made is clear, the scope of the study is clear, and the assumptions made supported by reliable data.
- be inclusive such that the extent to which stakeholders are involved reflects, among others, the technical and societal significance and human health and environmental implication of the decision.
- use robust data with sufficient level of detail and take into account the impact of data uncertainties on the optimisation process.

The process of optimisation involves the assessment of the waste streams and inventory as well as the associated risks leading to potential impact on human and environment. Also, more information to be gathered are on waste characterisation, treatment, conditioning, storage, associated costs, stakeholders' involvement and legal issues. Indeed, the BAT is closely related to the ALARA principle while economic and social factors are taken into consideration. The BAT should be used to prevent/minimise the production of radioactive waste with regard to radioactivity and quantity and therefore reduce the environmental risk. Overall, the use of BAT should fit well into the strategies of radioactive waste management and plans.

The process to identify the BAT shall be properly documented such that there is sufficient detail to support the conclusions reached.

The operators are responsible for demonstrating the benefits of using BAT to achieve optimisation through management arrangement including selection of the qualified and experienced staff, definition of responsibilities, undertaking a proportionate and systematic determination of BAT, retrieving and recording the information for decision making, implementing the outcome compatible with regulation and keeping BAT under continuous review and update.

The *management arrangements* include documentation with the frequency to undertake or review BAT assessments and describing how the assessment will be undertaken, reviewed and approved.

The BAT *assessment* involves that the operators show the benefits in terms of people and environmental protection for both short- and long-term operation, maintenance and dismantlement.

Practically, for option appraisal, the operator must consider the impact of the selected option on how the waste will be generated, managed, discharged and disposed of throughout the lifecycle of the facility and the site. Also, the operator needs to quantify the waste generation and disposal together with the resulting radiological impact in term of individual and collective exposure. The operator should consider all relevant risks (e.g. chemical, biological), impacts and uncertainties.

The operator should use standards, guidance and good practice to all aspects of operation including managements systems, maintenance, record keeping, etc. This applies for both new and existing facilities. The cost-benefit must not be taken as the main parameter to avoid using the relevant good practice. Also, lower standards or delaying the implementation of BAT cannot be accepted based on operators own financial position. Nevertheless, the regulator should not impose stricter standards than BAT.

In term of *recording* the optimised outcomes the process should be properly documented with sufficient details supporting the conclusions. The operators need to provide documents justifying the techniques determined as the BAT.

Upon approval of the optimisation process, the operator must put in place the management systems to allow the use of the determined BAT. The *implementation* process must be monitored for proper use of the BAT thus ensuring that the discharges and the resulting radiological impact complies with the ALARA principle. Finally, the BAT should ensure that the wastes arising from accidents or maloperations can be properly managed according to the optimisation process.

Finally, the use of BAT should be kept under review in response to changes with regards to the management and disposal of radioactive waste, in legislation or policy, availability of new knowledge about the impacts of radioactivity on people and environment, technology development, and switching from operation to decommissioning. When needed, operator should undertake BAT assessment process and demonstrate the justification of the selected BAT.

During the planning phase, many issues of the Optimisation DI are closely related to other EURAD Roadmap Domains: Inventory (2.1.1), Waste Acceptance Criteria (2.1.2), Waste Hierarchy (2.1.4), Characterisation (2.1.2), Treatment & Processing (2.2.2), Conditioning (2.2.3), Transport (2.2.4), Storage (2.2.5), and Technology Selection (2.1.3).

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3.2 Program Implementation

During implementation phase, it is essential to keep monitoring the robustness of the BAT like the capability to cope with updated regulations or waste streams. For instance, the selected technologies for waste treatment or conditioning should comply with updated regulations, which may establish new radiological and chemical characteristics of the waste forms arising from residues conditioning. In addition, financial risks associated to technologies adjustment must be taken into account.

The process described in section 3.1 should be applied during the implementation phase to re-assess the selected technologies using the new information/data from the BAT assessment. This must consider all the parameters such changes in regulations, evolution of repository concepts and technologies, plant lifetime as well as interim storage.

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3.3 Program Operation and Closure

During the operation of (pre-disposal) waste management facilities, continuous improvement of the technologies and processes based exist based on outcomes of the BAT assessment as described in sections 3.1 and 3.2. Feedback of technologies deployment during operation are valuable for improving performance in term of waste reduction and compliance with new regulations. The opportunity of extending plant lifetime should be considered. All the management and technical reports with sufficient details should be compiled and easily traceable for end of life and plant dismantlement. Feedback and lessons learned should also be documented as input data for future technology development.

During the operation phase, Optimisation issues closely link to the other EURAD Roadmap Domain of Waste Acceptance Criteria (2.1.2), Quality & Management Systems (2.3.1).

4 CRITICAL ISSUES, INFORMATION, DATA OR KNOWLEDGE IN THE DOMAIN OF OPTIMISATION

A holistic approach of optimisation is clearly lacking and needs to be developed with strong cooperation between all stakeholders (waste producers, WMO, regulators, etc.).

Optimisation of predisposal management of radioactive waste has been addressed in the OECD-NEA Joint workshop (2021). The workshop helped fostering discussions among participant including regulators, operators, policymakers, waste producers and decommissioning entities from different background to promote a holistic development and optimisation of predisposal radioactive waste management programs. Important topics consisted in understanding the impact of several factors covering the technical, legal, economic and societal factors on the fuel cycle systems and associated waste arisings for optimisation management. The key messages and conclusions are:

- The scarcity of literature on optimisation of the system (e.g. fuel cycle) as a whole. In this respect, some literature is available for fuel management (IAEA, 2019). The publication addresses: (1) good practices relevant to interim storage of nuclear research reactors spent fuel, (2) experience on lifetime management including extension of interim storage and (3) suggestions for further optimisation of effective and safe storage of the spent nuclear fuel by proposing new approaches.
- A key input for any optimisation process is the identification of what should be optimised and for whom, depending on the operator needs.
- Strong coordination is needed among all stakeholders to address the optimisation process as a whole (waste producers, WMO, regulators, etc.).
- Optimisation of waste generation should be addressed well upstream of generation with many drivers (reduction of cost, dose, volume, etc.). Drivers may be different in different countries.
- Requirements for regulating radioactive waste should ensure a balance between the required level of safety and economics needs.
- Critical challenges related to regulation and operation of waste management programs over long time scales, needs to be taken into account. It includes funding availability, knowledge management (e.g. training), regulation evolution and social expectations, etc.

Decision-making based on the process of optimisation described earlier can clearly help facing the above challenges.

5 MATURITY OF KNOWLEDGE AND TECHNOLOGY

The principles and process of optimisation have been partially documented, but not necessarily in a holistic manner for radioactive waste. As concluded in the NEA report (NEA/RWM/R(2020)3), it is recommended to develop guidance/information material concerning the optimisation, which comprises the following aspects:

- Creation of a consistent terminology that allows proper discussion on the subject.
- Publish a document to introduce the concept of predisposal optimisation, so that different stakeholders, including the general public can understand it clearly. This addresses two points:
    - Guidance documentation to the nuclear community to allow waste minimisation beyond the actual point of generation, thus contributing to the holistic optimisation of RWM.
    - An informative document for the public usable by all levels of society, including decision-makers, with the aim of raising awareness towards RWM optimisation opportunities.

6 PAST RD&D PROJECTS ON OPTIMISATION

There is no specific projects on optimisation in a holistic context. Nevertheless, several European Commission funded projects addressed aspects of optimisation for specific steps of radioactive waste management process (e.g. treatment, conditioning, and disposal).

- FP7 EURATOM - CARBOWASTE (2008-2013): The Treatment and Disposal of Irradiated Graphite and other Carbonaceous Waste (CARBOWASTE) project was focused on the development of guidelines to support the retrieval, treatment and disposal of irradiated graphite.
- H2020 - THERAMIN project (2017-2020): The objective of the Thermal Treatment for Radioactive Waste Minimisation and Hazard Reduction (THERAMIN) project was to provide improved safe long-term storage and disposal of intermediate-level wastes (ILW) and low-level wastes (LLW) suitable for thermal processing.
- EJP EURAD (2019-2024): Among the different WPs of the EU Joint Programme on Radioactive Waste Management (EURAD), WP9 (ROUTES) aimed to describe and compare the different approaches to characterisation, treatment and conditioning and long-term waste management routes between MS (member states), to identify relevant R&D topics which could be collaboratively launched in the second wave of EURAD [EURAD ROUTES D9.12]. The deliverable summarises the knowledge and approaches regarding the sharing of technology and facilities between countries in different steps of the waste lifecycle.
- HORIZON EUROPE – HARPERS (2022-2025): The overall goal of the HARPERS “HARmonised PracticEs, Regulations and Standards in waste management & decommissioning” project is to establish and clarify the

benefits and added value of more aligned and harmonised regulations, practices and standards in decommissioning and radioactive waste management, including possibilities for shared processing, storage and disposal facilities between EU Member States.

7 UNCERTAINTIES

Uncertainties for optimisation depend on those related to the different steps of radioactive waste management. Technologies for treatment and conditioning for a variety of waste are well advanced with minimal uncertainties. Nevertheless, there are still challenges due to some waste streams including graphite or organic waste with no mature technologies. Characterisation is a key challenge where decommissioning plans cannot be developed in detail without understanding the challenge. Techniques for in-situ characterisation often need development; therefore characterisation is limiting to human intervention and sampling campaigns. Other challenges may be linked to the extent of coordination between of stakeholders to conduct the process of optimisation as whole and not as an organisation dependent process. Also, issues related to funding availability may increase the uncertainties.

8 GUIDANCE, TRAINING AND COMMUNITIES OF PRACTICE

This section provides links to resources, organisations and networks that can help connect people with people, related to the domain of optimisation (treatment, conditioning).

Guidance
• IAEA (1992). Treatment and conditioning of radioactive solid waste. International Atomic Energy Agency, IAEA-TECDOC-655. online • IAEA (1992). Treatment and conditioning of radioactive organic liquids. International Atomic Energy Agency, IAEA-TECDOC-656. online • IAEA Safety Guide GS-G-3.3 - The Management System for the Processing, Handling and Storage of Radioactive Waste (2008) online • IAEA General Safety Requirements GSR Part 5 – Predisposal Management of Radioactive Waste (2009) online • IAEA General Safety Guide GSG-3 - The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste (2013) online • IAEA Specific Safety Guide SSG-40 - Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors (2016) online • IAEA Specific Safety Guide SSG-41 - Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities (2016) online • IAEA, 2017. Selection of Technical Solutions for the Management of Radioactive Waste. IAEA Tecdoc-1817, Vienna

• IAEA Safety Guide SSG-45 - Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education (2019) online • NEA - Recycling and Reuse of Materials Arising from Decommissioning of Nuclear Facilities, NEA No. 7310 (2017) online • NEA - Optimising Management of Low-level Radioactive Materials and Waste from Decommissioning, NEA No. 7425 (2020) online • NEA – Multifactor Optimisation of Predisposal Management of Radioactive Waste, NEA/RWM/R(2020)3
Training

• The IAEA offers 12 online learning courses on spent fuel and radioactive waste management, decommissioning and environmental remediation. These courses consist of 50 modules and almost 100 lectures. They are free of charge and intended for anyone looking to understand the fundamentals of these topics, including young professionals and new entrants to the respective areas. link
Specific e-learning modules for Radioactive waste treatment are under preparation.
• Training courses on Radioactive Waste Management are organised by different organisations and include treatment and processing topics. Some of them are here reported:
  o SCK-CEN - Training course on radioactive waste management (link)
  o ENEN - Winter School on Nuclear Waste Safety and Management (link)
  o INSTN, international school in nuclear engineering: nuclear waste management module. online
  o TÜV Italia Akademie - Nuclear Safety with Respect to Radioactive Waste Management Facilities (link)
  o EU - Summer School on Nuclear Decommissioning & Waste Management (ELINDER Course G5) (link)

Active communities of practice and networks
• NUGENIA (Nuclear Generation II & III Alliance), Technical area 5: waste management and decommissioning, https://snetp.eu/nugenia • World Nuclear Association - Waste Management & Decommissioning Working Group monitors developments and shapes industry positions with a view to improving the system of waste management and decommissioning. In 2019 a report that highlights the key principles and stages of efficient waste management processes and good practices was published: “Methodology to Manage Material and Waste from Nuclear Decommissioning”, 2019 online • IAEA International Radioactive Waste Technical Committee (WATEC) https://www.iaea.org/resources/databases/watec • Western European Nuclear Regulators Association (WENRA), working group on waste and decommissioning (WGWD) (https://www.wenra.eu/wgwd)

9 ADDITIONAL REFERENCES AND FUTURE READING

Environmental Agency. RSR : Principles of optimisation in the management and disposal of radioactive waste. www.environment-agency.gov.uk.

IAEA, Classification of Radioactive Waste, IAEA Safety Standards Series No. GSG-1, IAEA, Vienna (2009).

IAEA, Practices for interim storage of research reactor spent nuclear fuel. IAEA Nuclear Energy Series No. NF-T-3.10 (2019).

Nuclear Energy Agency (2021). Multifactor Optimisation of Predisposal Management of Radioactive Waste. Proceedings of the NEA Joint Workshop, 10-14 February 2020, Paris (NEA/RWM/R(2020)3).