2. PREDISPOSAL ACTIVITIES PRIOR TO GEOLOGICAL DISPOSAL OF WASTE; THEME OVERVIEW

In conjunction with waste generators, identify and deliver solutions to optimise the management of radioactive waste throughout the predisposal phases of the radioactive waste management programme

INTRODUCTION

All EU Member States (MS) produce radioactive waste (RW) resulting from not just operation and decommissioning of nuclear facilities but also from the use of radionuclides in medicine, industry, agriculture and research as well as processing of raw materials containing naturally occurring radionuclides. The ultimate requirement is for all material that cannot be freely released to then be permanently disposed in an appropriate facility according to their waste classification. This can range from conditional release to disposal within a geological repository, including radioactivity from very-low to high-level wastes. Yet before disposal, there are typically predisposal activities done to improve the safety, efficiency and environmental impact of the waste's final disposal. The waste characterisation and processing phases within the predisposal activities are primary focuses, where physio-chemical actions are implemented for spent fuel reprocessing, waste reduction, treatment/conditioning and packaging. These actions are often taken to support the waste hierarchy of minimising the disposal volumes of higher activity material. The situation also exists when predisposal actions purposely generate smaller volumes of higher activity waste (e.g. through decontamination or reduction) at the advantage of reducing higher volumes of lower active wastes. There are a variety of complimentary actions associated with storage, transport and planning associated with the waste lifetime that also factor into the holistic predisposal management.

A national radioactive waste management (RWM) program has a defined owner of the waste inventory, which may change over time and through the programme between the waste generator, a processing company, a waste management organisation, or even the national government. Predisposal waste management activities can be implemented at many phases during the waste transfer between the generator, waste owner and the final waste disposal facility owner/operator, thus iterative communication and documentation is a factor of success. A national RWM programme should establish the policies associated with predisposal waste management, as described within Theme 1 Programme Management. Through all phases and predisposal activities, there are also continuous planning activities associated with evaluating the waste inventory evolution, technology availability, economics and a life cycle approach, as also noted within Theme 1 Programme Management.

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KEYWORDS: predisposal, inventory, characterisation, sorting, classification, processing, treatment, decontamination, conditioning, storage, monitoring, transport, disposability assessment, waste acceptance criteria, waste hierarchy, free release, recycling

KEY ACRONYMS: GBS - goals breakdown structure; DGR - deep geological repository; IAEA - International Atomic Energy Agency; MS - Member State; NDE - non-destructive evaluation; NPP - Nuclear Power Plant; RW – radioactive waste; RWM - radioactive waste management.

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TYPICAL GOALS PURSUED IN PREDISPOSAL WASTE MANAGEMENT

This section provides a goals breakdown structure (GBS) for the EURAD roadmap Theme 2 on predisposal. It is organised in a hierarchy of 3 levels according to theme → sub-themes → domains. The GBS is in alignment with the IAEA nomenclature and GSR 5 (IAEA 2009b) and Figure 1 (See below). The Level 2 sub-themes are categories that tie to overall National Programme Management, which is covered more extensively in the EURAD roadmap Theme 1.

Theme (Level 1)	
2. In conjunction with waste generators, identify and deliver solutions to optimise the management of radioactive waste throughout the predisposal phases of the radioactive waste management programme (Predisposal)	
Sub-themes (Level 2)	**Domains (Level 3)**
2.1 Planning predisposal management of radioactive waste in close cooperation with waste generators (Planning)	2.1.1 Evaluate waste inventory from generators and existing storage, accounting for future waste generation and evolution (Inventory)
	2.1.2 Identify parameters and metrics for waste acceptance criteria through whole life cycle (waste acceptance criteria)
	2.1.3 Assess potential technologies for the implementation phase, considering cost-benefit ratio and availability (technology selection)
	2.1.4 Evaluate options to apply the waste hierarchy to minimise waste volumes at higher impact inventory disposal levels (waste hierarchy)
2.2 Implementing predisposal management of radioactive waste to support key risk and hazard reduction, and to help reduce costs and save space at interim storage and disposal facilities (Implementation)	2.2.1 Sort, characterise, classify and quantify radioactive waste in accordance with requirements established or approved by the regulatory body (Characterisation)
	2.2.2 Minimise the quantity and volume of radioactive waste through pre-treatment and treatment (Treatment & processing)

	2.2.3 Stabilise waste by conditioning prior to long-term storage (Conditioning)
	2.2.4 Package waste accounting for future transport and deposition, and maintain safe interim storage of packages (Storage)
	2.2.5 Transport radioactive wastes between facilities in accordance with regulatory requirements (Transport)
2.3 Enhancing predisposal operations through iteration with waste generators and repository operators, to develop and deliver safe and cost-effective solutions (Optimisation)	2.3.1 Implement quality system and management system to ensure accurate detailed records of waste and package characteristics over their lifetime, from production until deposition (Quality & Management Systems)
	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)
	2.3.3 Manage secondary waste streams produced during initial processing, for lifecycle approach (Secondary Waste Management)

TYPICAL ACTIVITIES IN PREDISPOSAL WASTE MANAGEMENT

A predisposal waste management programme owner aims at safely minimising wastes and preparing it for release or disposal. The holistic predisposal programme activities are summarised in Figure 1.

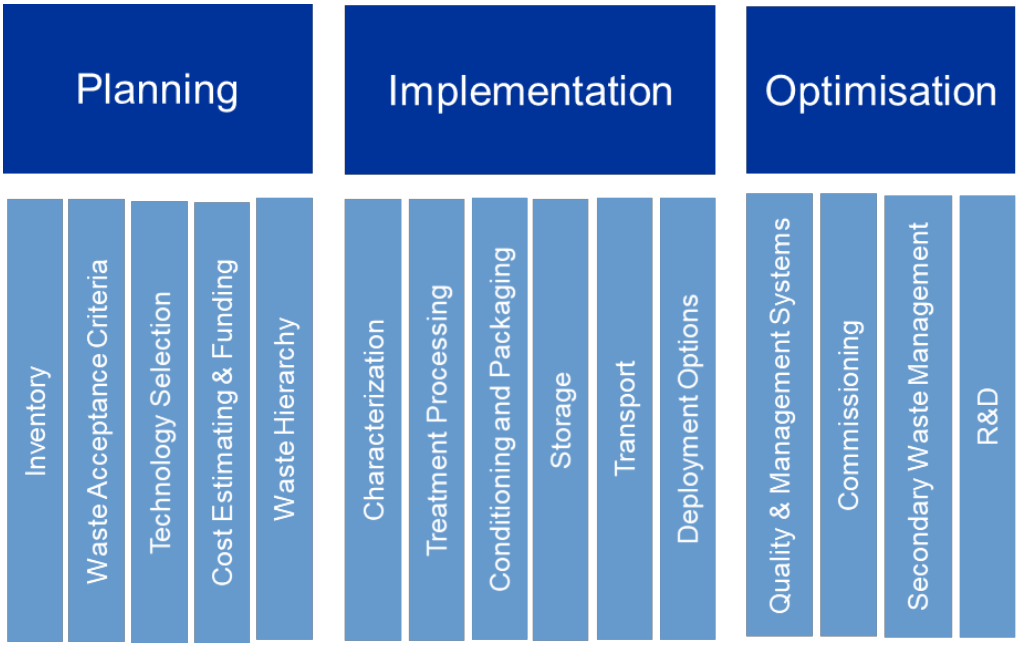

Figure 1: Principle predisposal waste management programme activities. (Reproduced courtesy of IAEA © 2020)

The predisposal activities require detailed planning prior to actual implementation, while continuously evaluating the operational outcomes expected from the predisposal activities. Before the predisposal core actions of processing can occur, it is critical for the waste owner to assess the waste inventory that has been generated, planned waste stream composition or evolution over time, and feasibility of technologies to be applied in line with economic constraints and with further steps down the waste management chain (including final disposal). There needs to be close and continuous knowledge exchange regarding the planned final geological repository requirements, focused on the waste acceptance criteria of the waste inventory and packages. After thorough planning and in accordance with national policies and regulatory requirements (see, Roadmap Theme 1), the actual predisposal activities can commence. The owner needs to characterise the waste before and after any processing actions, then package waste into containers for storage, transport and potential direct disposal (see, Roadmap Sub-Theme 3.2). Processing actions includes pre-treatment (such as minimisation), treatment (such as by reprocessing of spent fuel, thermal or chemical processes of wastes) and conditioning (such as immobilisation). Secondary waste streams that may result from the processing of the primary waste stream must also be handled in a safe and efficient manner. The owner and all parties associated with the waste streams should maintain detailed radiological-physio-chemical inventory and activity data logs for safety and quality management over the waste stream's potentially long life-cycle from production to disposal (see, Roadmap Sub-Theme 1.4). A waste owner needs to check if sufficient interim storage capacity in dedicated facilities is available and prepare logistically for transport and record keeping that may span decades until final disposal facilities are available. Owners having waste and/or packages within extended periods of interim storage may be required to implement monitoring programmes to demonstrate the waste's stability, durability and safety, also associated with potential accidents or threats. There is a need for cross-border awareness on waste acceptance criteria if any phases of the predisposal implementation activities involve international services. As the predisposal waste management programme evolves, efficiency in the operational environment can include optimisation and further commissioning of new technologies as part of the

predisposal actions. The owner needs to assess the evolution of the waste characteristics that may result from introducing new processes that would lead to waste which cannot be further treated, conditioned, or accepted for final disposal. As the national programme advances towards readiness of geological disposal facilities, it is critical that continuous communication is maintained with the predisposal waste owner to ensure compliance with waste acceptance criteria, regulatory requirements and safe disposability. Within Figure 1, some issues such as cost estimation and funding, quality systems and research and development (R&D) strategies fall within the overall national program management, and thus are covered within Theme 1 of the EURAD roadmap. Other examples of the predisposal activities are visualised in Figures 2 and 3 over the waste management lifecycle.

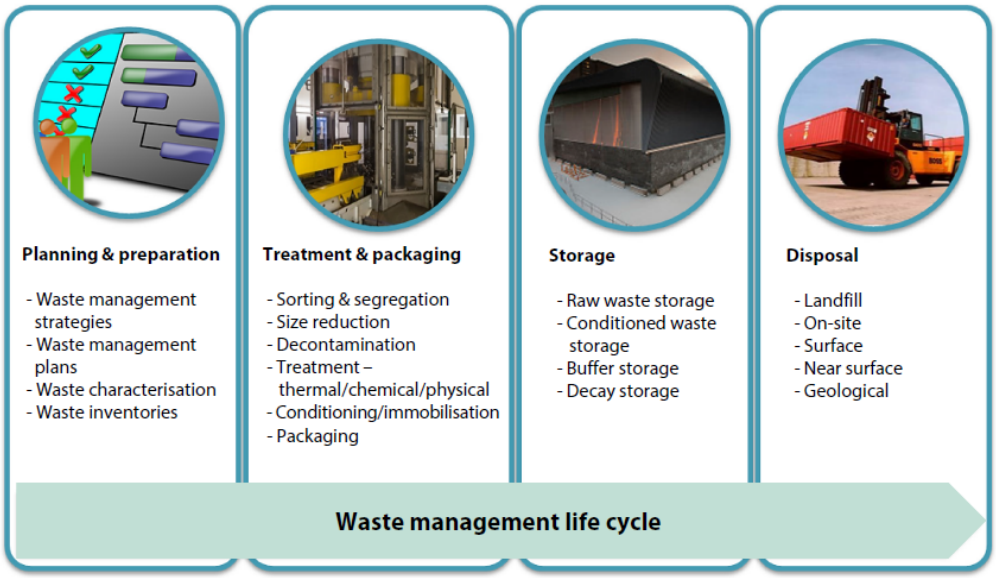

Figure 2: Typical LLW life cycle (OECD/NEA 2020)

2. PREDISPOSAL; THEME OVERVIEW

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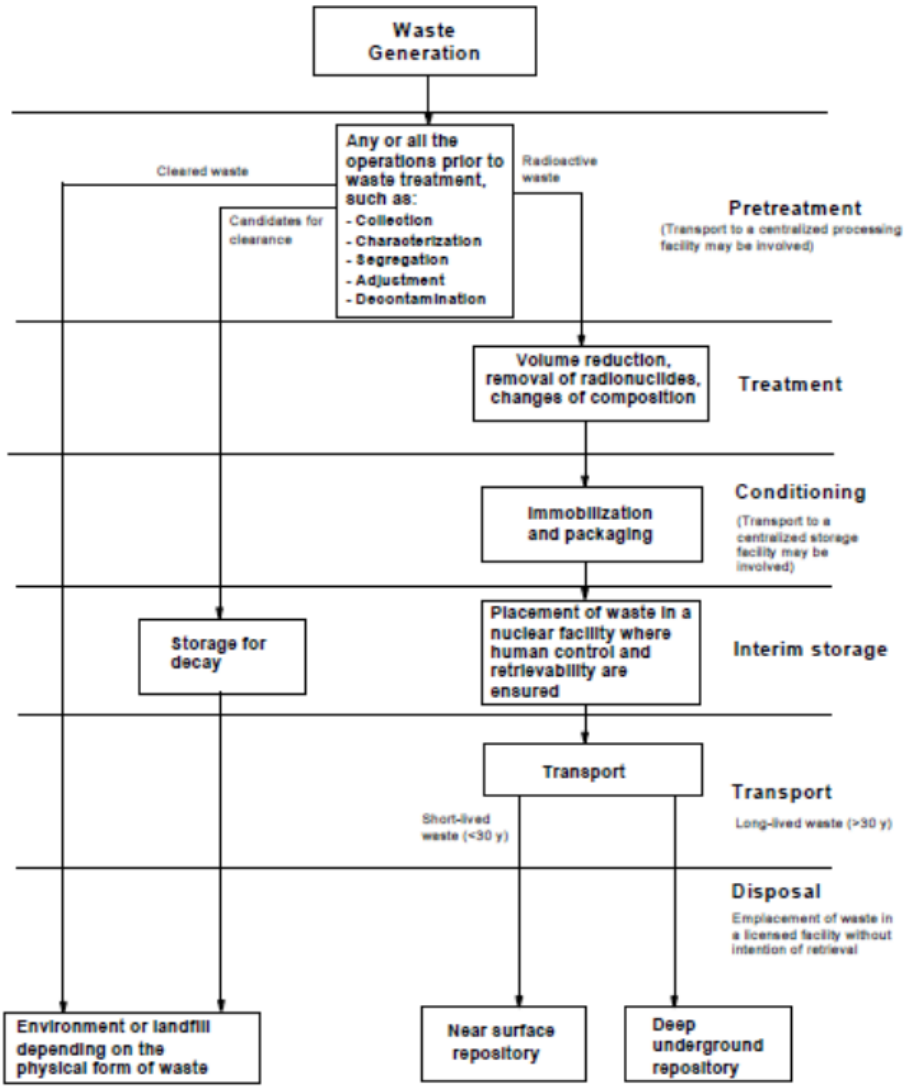

Figure 3: Waste management steps (IAEA 2003).

RECOMMENDED PREDISPOSAL ACTIONS OVER PHASES OF IMPLEMENTATION TOWARDS FINAL DISPOSAL[1]

This section provides examples of typical actions completed in predisposal, over different phases of implementation. The phases refer to the whole RWM programme with respect to predisposal management, not to the phases of DGR implementation.

Planning and Programme Initiation (Phase 1)

Predisposal Management

Liaison with waste generators to document current and future anticipated waste inventory of waste material types, radioactivity, volume, location. Compare predisposal processing technology options with respect to economic and environmental life cycle parameters. Evaluate spent fuel re-processing options as well as free-release and recycling opportunities for very low radioactivity materials, to avoid disposal altogether in accordance with the waste hierarchy (Figure 4). Understand regulatory requirements for both predisposal and disposal aspects and prepare documentation for predisposal processing facility operation licensing. Plan investments as needed for infrastructure and competences as needed for implementation. Document existing interim storage facilities for wastes and packages, and predisposal waste transport routes. Foster transparent communication with stakeholders regarding locally planned processing facilities, storage and transport of wastes, and addressing any concerns stakeholder may raise. Evaluate overall program schedule and technologies, to assess if near-term actions should be taken or rather postponement of program actions due to uncertainties associated with future management steps of the waste. For instance, if the final disposal system concept and design is not mature, it may pose challenges if the waste is conditioned then interim stored for longer periods compared to performing the same characterisation of the waste inventory when the waste is still in its raw form.

Disposability Management

Prepare for combination of materials to be received from potentially many waste generators, predisposal treatment companies or storage facilities. Evaluate holistic waste inventory and classification for all materials to be disposed to the final disposal facility. Identify parameters needed within waste acceptance classification to meet future disposability of all categories of waste (from very low- to high-level radioactivity), accounting for national policy and regulations. Design characterisation facilities and schemes for these parameters. Establish quality management system to record and transfer these parameters to future steps of the waste management chain. Consider geological site suitability or uncertainties that may influence waste package designs and their safety factors. Survey international best practices. Evaluation of economic scenarios that link pre-disposal actions to disposability requirements for program lifetime.

[1] Disposal here refers to facilities taking any waste forms, from very-low, to low-, medium- and high-level radioactivity wastes. Thus disposal refers to being in a deep geological repository (DGR) and/or other shallow or sub-surface repositories.

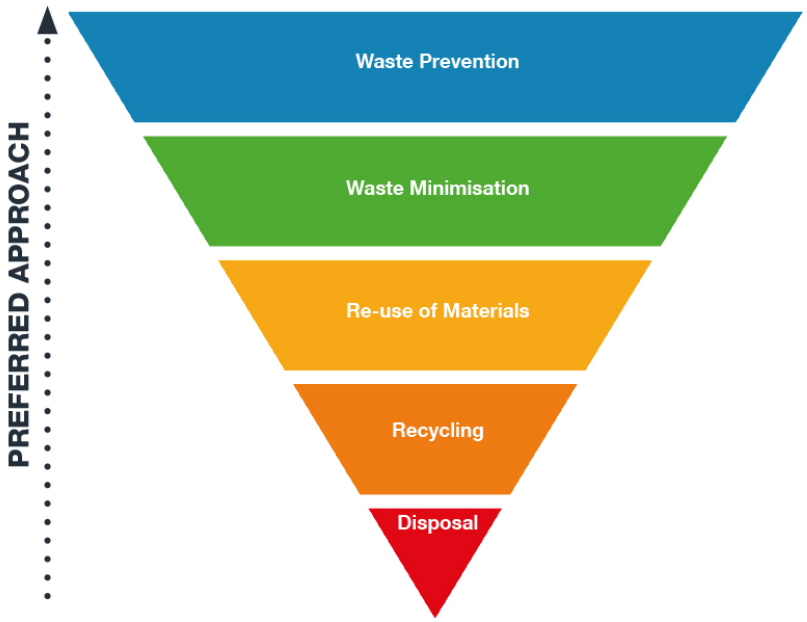

Figure 4: Waste hierarchy. (NDA 2020)

Programme Implementation (Phase 2)

Predisposal Management

Implementation of operational predisposal management facilities, including accepting, sorting, characterising, processing and packaging of waste. Arrange transport and interim storage of waste and packages, including quality assurance via a monitoring program. Maintain detailed records of waste history, inventory and processing, as well as continued information exchange with waste generators on evolution of waste inventory. Maintain communication with local and national stakeholders, including safety reviews with regulatory body for continued licensing of facility operation.

Disposability Management

Establish preliminary and then detailed waste acceptance criteria, in consultation with waste generators, with attention to regulatory requirements. Communicate to repository owner on waste package parameters, linked to radionuclide inventory needed for preliminary repository dimensioning, environmental impact assessment and safety case models. Implement waste transport and delivery logistics between waste generator, waste owner during predisposal and then readiness for geological repository deposition. Prepare facilities for accepting and handling waste packages prior to disposal, including possible encapsulation plant. Prepare and obtain required regulatory licenses, for instance for design, construction and future operation of repository.

Programme Operation / Optimisation and Closure (Phases 3-4)

Predisposal Management

Enhance the operation described in the previous phase of implementation, by optimising the whole predisposal cycle. Ensure responsible management of secondary waste steams produced during processing. Ensure high quality system of managing records of the waste from cradle to grave. Finalise how parameters of waste processing and waste packages must be accounted for in the final repository detailed design and safety case. Evaluate how new predisposal waste processing techniques and changing regulations can have positive impacts on overall inventory and packages, including economic and environmental indicators. Evaluation of any re-processing and/or re-packaging needs of wastes in interim storage to fulfil updated final disposal requirements or repository detailed designs. For instance, raw waste that has already been processes and conditioned at a much earlier date may need the waste form and package integrity to be re-evaluated to ensure that it complies with disposability readiness. Evaluation and waste form characterisation can be with various forms of non-destructive evaluation (NDE) or intrusive techniques for assessment.

Disposability Management

Implement package quality control prior to transport of waste to the final disposal repositories. Prepare for possible transfer of ownership of the waste to the repository operator, including quality management, records and regulatory review responsibilities. Update waste acceptance criteria if needed, based on operational learnings and/or waste generator inventory evolution. Eventually communicate closure activities of the processing facilities and storage facilities.

AVAILABLE CAPABILITIES: STATUS AND OUTLOOK

This section describes programme capability needs (including infrastructure) that are required to successfully complete the activities and actions recommended to achieve generic goals on predisposal waste management.

Knowledge and understanding

The competences associated with predisposal management have overlaps to nuclear power plant operations, decommissioning, and final geological disposal planning and operations. The required competences are linked to the type of actors involved. A national RWM programme or waste owner needs to have the core capability for understanding their overall waste inventory, the waste characteristics and the associated waste acceptance criteria for their national policy and repository requirements. They need to know how to characterise the wastes and what treatment and conditioning facilities exist nationally or internationally. They need to make decisions on predisposal waste management based on the most economical solution, also accounting for social-economic aspects, to achieve an end product compatible with regulatory requirements from the national RWM programme and/or regulator. They should have an understanding of the eventual disposability concept and system requirements, and be able to accurately communicate with the waste management organisation responsible for final disposal. The core capability of the waste owner during predisposal phases can also be linked to the regulatory reviews for operational approval of facilities and persons handling the predisposal waste management activities.

Core capability in predisposal management is associated with the processing of the waste streams, including chemical and physical property changes to the waste. In **addition,** there are a range of skills needed related to waste characterisation, sorting, packaging and storage. Some of these competences are found directly with the waste producing organisation such as an operating nuclear

power plant that changes scope towards decommissioning. It is feasible to educate and develop competences from in-house towards more intensive predisposal management needs as the waste inventory and processing urgency increases. Typical technical competences utilised in these predisposal waste activities that will continue to be needed for decades to come and should be emphasised during training and/or recruitment programmes include: radiochemistry, chemistry, physics, material science, numerical modelling, statistics, civil engineering, mechanical engineering, monitoring and data handling, transport, logistics, communication (stakeholder engagement).

Domain-level experts and practical skills

Due to the extensive experience of many European Member States with industrial radioactive waste handling and NPP operations for many decades, there is high capability with respect to both knowledge and infrastructure available for predisposal waste management to handle traditional types of wastes. It is acknowledged that there are still some problematic waste streams such as graphite with no industrial mature predisposal (and disposal) solutions, which is the subject of on-going discussions, research, development and investments. There are also expected to be high volumes of waste generated during NPP facility decommissioning in the next decades, which will increase the demand for more timely and cost-efficient predisposal capabilities. With respect to competences, there are experts who are practicing in public and private sector companies in this domain, with availability of new persons with relevant skills continuously entering the market. There is a wide range of guidance documentation available on predisposal methodology, best practices and technologies. The decision for a country or company to invest in their own predisposal management know-how is highly dependent on their inventory size and complexity. The decision to develop in-house (or in-country) technologies, infrastructure and competences for predisposal processing capacity should depend on the cost-benefit ratio compared to utilising international services.

Laboratories and centres of excellence

Companies that are offering predisposal waste management can be found by international trade registries, associations such as SNETP (Sustainable Nuclear Energy Technology Platform) and the World Nuclear Association , and via their participation at trade fairs on decommissioning and waste management. Many relevant laboratories are cooperating within the Euratom project "PREDIS: predisposal management of radioactive waste" (2020-24).

Equipment, tools and technology

As written in the previous section, due to years of EU Member States' experience in NPP operation including predisposal waste management, there are numerous mature technologies and services available on the international market. Some countries and companies have been operating predisposal waste management facilities for decades, including interim storage and final disposal or even free release of wastes re-used by other industries. Yet the predisposal waste management ready technologies and market offerings are very dependent on the type of waste-stream and location. There are significant market opportunities for new companies to provide new technologies and services in the predisposal field, with high market costs and potential profits associated with predisposal processing. Equipment, tools and mathematical models for rapidly and accurately characterising wastes, even while in-situ (for instance in existing NPPs undergoing decommissioning or storage facilities or structures where historic documentation is lacking), will improve efficiency of the processing. There is the ability of knowledge

transfer between industries associated with decommissioning and even materials/mineral processing, for instance growing with the increased emphasis on circular economy of generic material streams' treatment and re-use. Within the market offering, it is acknowledged that there are some problematic waste streams, such as graphite materials from reactor decommissioning, which are still at the research and development stage for predisposal processing prior to disposal. The sorting, characterisation, processing and packaging of such types of waste is not market-ready. Technologies for ventilation and fire security are assumed to be mature enough and can thus be taken from the open market.

Industrial facilities and manufacturing

There is a small risk of infrastructure availability over the next decade due to increasing demand, though higher risks associated with equal access and competitive pricing. Infrastructure associated with predisposal management include facilities for waste characterisation, reprocessing, predisposal processing, logistics centres for coordinating transport (road, sea, air) and storage facilities for both waste and packages. Some facilities handle spent fuel reprocessing, and there is currently only one available in Europe (France) after the closure of the UK facility. The processing facilities can include a variety of activities associated with for instance collecting, segregating, reprocessing, decontamination, volume reduction, immobilization, characterisation, and packaging. There is computing infrastructure needed for monitoring and collecting data, long-term data storage, modelling, data interpretation and quality control archives. The infrastructure may be localised near the waste generator or can be centralised for combined use. As the volumes of waste increase (i.e. associated with NPP lifetime extensions having more waste from maintenance activities and then eventual decommissioning), there will be greater demand for infrastructure associated with predisposal management and storage of wastes. The worldwide construction of new NPPs and Small Modular Reactors (SMRs) may influence the demand for fuel and re-processing capacity.

Across Europe there are problematic waste streams that are challenging to characterise and/or process (such as graphite), and thus new technologies are continuously under development. For some waste streams, there are only a few international companies offering predisposal processing, and thus there can be high costs and time requirements associated with getting such service. There can also be complexities due to cross border waste transport and regulatory compliance when utilising international services of waste processing. Increasing the market capacity and efficiency in predisposal processing infrastructure will benefit Member States, especially those with smaller waste inventories. Another area of capability need is the development and deployment of mobile waste processing facilities that can be transported to a localised waste site, to avoid transport of radioactive waste streams. Such facilities would enable a wider range of access to predisposal processing while minimising transport of waste and potentially reducing cross-border regulatory oversight. There is expected to be increased demand for such mobile infrastructure and business offerings in the next decade(s) associated with increased NPP decommissioning.

As predisposal waste management progresses steadily, additional capacity is needed at interim storage facilities while final geological disposal facilities are prepared. Thus, record and quality management for knowledge on the waste inventory over time, especially from the time of waste generation at the original industrial site, could be at risk within a programme due to the predisposal management's potentially long-time scales of decades that faces retirements and generation changes in leadership. It may be harder for smaller companies or countries to maintain high-level expertise competences in predisposal processing due to mobility of resources to larger bodies, due to the shortage of persons in this field.

Figure 5: Safe and secure storage of radioactive waste at Research Sites Restoration, Harwell, UK (photo D. Calma/IAEA)

Contractors and human/material resources

There is a low to medium level risk of critical knowledge shortage. Knowledge on predisposal waste management is associated with nuclear power plant (NPP) operators, operators of centralised storage facilities and/or treatment facility operators. As the European fleet of NPPs age, policies change and more plants are being decommissioned, there is a growing need for waste handling expertise. There is a risk that experts are no longer motivated to remain in, or younger professionals are not entering the nuclear field due to ceased plant operations, yet at the same time there will be an exponential demand for predisposal waste management competence.

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