2.2.4 Storage, Domain Insight

Package waste accounting for future transport and deposition, and maintain safe interim storage of packages (Storage)

Theme 2: Pre-disposal

Sub-theme 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

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OVERVIEW

Storage is an essential component of the radioactive waste management (RWM) lifecycle and provides a safe, secure environment for waste, materials and spent fuel awaiting treatment, conditioning or packaging, and for packaged waste awaiting final disposal. The objective of this overview document is to provide guidance focused on storage issues in the pre-disposal stage of waste management.

National policy decisions influence the waste management strategy and requirements for storage of radioactive waste (RW) and spent fuel. If disposal facilities are already available, storage may only be required for short timescales or smaller volumes of waste. However, currently many EU member states (MS) require interim storage of significant proportions of their RW, depending on the end point of the waste. The end point could include recycling, treatment, reprocessing or deposition in a near-surface disposal facility or deep geological repository (DGR),

Some EU MS consider that nuclear materials such as uranium, plutonium and spent fuel could be a future asset and are storing them to keep options open while technologies are developed or implemented. Some MS already have a closed fuel cycle and reprocess spent fuel, extracting the uranium and plutonium for reuse in

These projects have received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreements n° 847593 and n°945098.

MOX fuel and storing the resulting vitrified high-level waste (HLW), while others have an open, or once-through, fuel cycle, where the spent fuel is placed into storage while awaiting disposal.

Storage duration ranges from several years up to over 100 years. In many EU MS (e.g. the UK, Belgium), interim storage facilities have been designed with 75–100-year lifetimes to allow for construction of a DGR [UK NDA, 2021; ONDRAF-NIRAS, 2022]. However, the Netherlands has a national policy of interim storage up to 2130 to enable financial investments to fund construction of disposal facilities and to keep the option open to share solutions with other countries [Ministry of Infrastructure and the Environment, 2016]. Italy is currently planning new centralised facilities for the long-term interim storage of intermediate-level RW and HLW prior to disposal [SOGIN, 2023] and Switzerland already has these in place at the ZWILAG facility [Nagra, 2016].

Technical features and quality control requirements for the waste packages and storage system should be established for the expected storage duration. Storage arrangements depend on activity of the stored material, whether heat generation or criticality need to be considered, and whether the waste package provides any shielding or criticality control or if this needs to be provided by the store building and internal furniture. Robust storage arrangements, including waste acceptance criteria and monitoring, provides high confidence that packages will be retrievable and disposable at the end of the storage period.

KEYWORDS

storage, predisposal, buffer storage, interim storage, long-term storage, safety, security, open fuel cycle

KEY ACRONYMS

GBS – goals breakdown structure

GSR – general safety requirements

HLW – high-level waste

DGR – deep geological repository

IAEA – International Atomic Energy Agency

MS – Member State

NEA – Nuclear Energy Agency, part of OECD

NPP – Nuclear Power Plant

PREDIS – Pre-disposal Management of Radioactive Waste (EC project)

RD&D – research, development and demonstration

RFID – Radio Frequency IDentification

RW – radioactive waste

RWM – radioactive waste management

SQEP – suitably qualified and experienced persons

WAC – waste acceptance criteria

WENRA – Western European Nuclear Regulators’ Association

1 TYPICAL OVERALL GOALS AND ACTIVITIES IN THE DOMAIN OF STORAGE

This section provides the overall goal for this domain, extracted from the EURAD roadmap goals breakdown structure (GBS). This is supplemented by typical activities, according to phases of implementation, needed to achieve the domain goal. Activities are generic and are common to most regional and geological disposal programmes.

Domain Goal	
2.2.4 Package waste accounting for future transport and deposition, and maintain safe interim storage of packages (Storage)	
Domain Activities	
Phase 1: Planning and Programme Initiation	Establish inventory, locations and configuration (i.e., raw or conditioned, suitability for direct disposal) of existing wastes and future arisings, packages, treatment and processing facilities, existing interim storage facilities. Establish location and timescales for subsequent management steps, including final disposal, if possible. Identify requirements for initial storage of unconditioned waste, spent fuel and materials, buffer storage during processing, decay storage and interim storage of conditioned waste prior to disposal, with attention to safety and stakeholder requirements.
Phase 2: Programme Implementation	Construction of on-site, regional or centralised storage facilities for raw waste (if needed), buffer storage associated with treatment and processing facilities, and interim storage facilities for packaged waste. Store lifetimes need to be considered in the context of the national inventory and national plans for final disposal.
Phases 3–4: Programme Operation/Optimisation and Closure	Manage iterative reviews and updates of store safety cases, responding to latest RD&D, technology developments for monitoring, security, potential need for rework or overpacking of damaged waste packages, retrieval of waste packages for transport to an appropriate end point, store decommissioning.

2 INTERNATIONAL LEGISLATION, REGULATION, AND REQUIREMENTS

International regulations on the safe management of RW are in place to ensure protection of people and the environment during the full lifecycle and security of radioactive materials and waste. For example, Directive 2011/70/EURATOM established a Community framework for the responsible and safe management of spent fuel and radioactive waste, adopted by the Council of the European Union on 19 July 2011. This provides binding legal force to the main internationally endorsed principles and requirements in this field. Requirements of EURATOM state that all EU countries need to have a national policy for spent fuel and radioactive waste management and that they draw up and implement national programmes for the management of these materials.

Specific to storage, the International Atomic Energy Agency (IAEA) Safety Standard Predisposal Management of Radioactive Waste: General Safety Requirements (GSR Part 5) establishes the safety requirements that apply to all facilities and activities that are involved in the management of RW before disposal, including storage facilities [IAEA, 2009]. The IAEA is also producing a safety guide (currently in draft) to support meeting the GSR's requirements, which identifies the need to consider security as well as safety [IAEA, 2019].

Requirements specific to the storage of RW and spent fuel are also set out in a report prepared by the Western European Nuclear Regulators' Association (WENRA) which details safety reference levels for RW and spent fuel storage facilities [WENRA, 2014], including:

- Safety management, organisation and records.
- Design.
- Operations, including receipt arrangements, inspection and maintenance, contingency planning and retrieval of waste packages at the end of the storage period.
- Safety verification, including development and updating of a safety case for the storage facility and its contents during the lifetime.

The IAEA and WENRA requirements noted above emphasise that "health, environmental, security, quality and economic requirements" should not be considered separately from safety requirements; an integrated system needs to be implemented to ensure an appropriate level of security without compromising safety and vice versa. In the context of interim storage, security is intended to prevent the unauthorised access of individuals and the unauthorised removal of radioactive material [IAEA, 2009].

Stores containing spent fuel and nuclear materials (e.g. uranium, plutonium) need to meet additional security and safeguards requirements. Safeguards are activities by which the IAEA (and EURATOM, for the EU) can verify that a MS is living up to its international commitments not to use civil nuclear power programmes for nuclear weapons purposes. These activities include nuclear material accounting, verification activities and inspections [IAEA, 2018; EC, 2005].

The NEA recently reviewed regulations, policies, strategies and financial issues in member countries, as well as best practices for storage of RW and spent fuel. More than five decades of experience have shown that surface storage facilities can provide safe and secure containment as long as the storage facilities are appropriately designed, constructed and maintained to ensure containment integrity [NEA, 2020].

In addition, it is recognised that each MS has their own national level regulations, which comply with IAEA regulations. Individual MS may also have their own protocols for evaluating or managing safe storage of radioactive materials.

3 GENERIC SAFETY ISSUES FOR STORAGE

This section describes how safety and security are considered for RW storage during each of the three phases noted in Section 1. They are described with respect to a waste management programme addressing pre-disposal activities (prior to final geological disposal).

3.1 Planning and Programme Initiation

In the early phases of pre-disposal programme initiation, it is essential to assess the waste inventory locations, the nature and quantities of the waste (including the physical, chemical and radiological properties), and the facilities that are anticipated (processing, treatment, storage, disposal). In this way, the safety[1], security[2], cost, legislative and stakeholder requirements applying to storage facilities can be identified and taken into account when identifying options.

The storage facility design is determined by the materials that require storage, the anticipated duration, and the types of wasteforms and containers to be stored. Low-activity and contact-handled RW, for which doses to operators do not prevent access, may be stored in:

- Tanks or pits for raw waste;
- Existing warehouses or similar weatherproof industrial buildings; and
- Unshielded or lightly-shielded concrete buildings.

Remote-handled RW, spent fuel and nuclear materials may be stored in:

- Shielded tanks or pits for raw waste;
- Charge-plug stores, where packages are stored in vertical tubes underneath a shielded charge floor, with active or passive ventilation and criticality control built into the store design;
- Reinforced concrete vault stores, where the store structure provides shielding and cooling (if required);
- Overpack or cask stores, where packages are placed into overpacks or casks that provide shielding and passive cooling (if required for vitrified HLW and spent fuel); and
- Wet or pond storage for spent fuel.

Facilities or components thereof that are expected to give rise to RW can also be decay-stored *in-situ* prior to retrieval, treatment and packaging to reduce the dose and risk encountered by operators during decommissioning; this is not explicitly considered in this overview document. In addition, for very short-lived radioactive wastes, it is possible to pursue a decay in storage approach. Here, waste contaminated with certain short-lived radioisotopes can be stored under suitable

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[1] The IAEA Safety Glossary [IAEA, 2007] defines Nuclear Safety as "the achievement of proper operating conditions, prevention of accidents or mitigation of accident consequences, resulting in protection of workers, the public and the environment from undue radiation hazards".

[2] Nuclear Security is "the prevention and detection of, and response to, theft, sabotage, unauthorized access, illegal transfer or other malicious acts involving nuclear material, other radioactive substances or their associated facilities" [IAEA, 2007].

conditions for a minimum of 10 half-lives. After this time, the waste is surveyed, and if no activity distinguishable from background levels is found, then it can be disposed of as non-radioactive waste. Ireland is an example of a country where this approach has been implemented [IAEA, 2021]. This approach is also not explicitly considered in this document.

Prior to developing detailed designs for new stores, the following aspects should be considered:

- Siting requirements, including the minimum size of the facility and engineering feasibility.
- Shielding, cooling and criticality prevention requirements if the waste, material or spent fuel requires remote-handling, is heat-generating or fissile.
- Security and (where applicable) safeguards requirements [IAEA, 2018].
- Design life, which should be based on timescales for availability of a DGR; good practice suggests this should be at least 100 years for new stores.
- Package import arrangements, including required throughput (number of packages per year) and ability to accept specific types of transport container, which are linked to the requirements of the donor facilities, the transport system and the disposal facility.
- Planning for retrieval of packages at the end of the storage period and decommissioning of the store facilities. Packages need to be retrievable and suitable for transport to and receipt by the appropriate endpoint (recycling, treatment, reprocessing or deposition). Rework or overpacking facilities may also be needed if any packages have been damaged during the storage period.
- Ability to develop a safety case, including consideration of external hazards and risks such as floods, earthquakes, tsunami, strong winds, climate change, malicious actions, aircraft impact, site-specific accidents (e.g., incident at neighbouring facility), snow/ice, animal action.
- Stakeholder acceptance of the facility, including any additional planning and permitting requirements necessary to secure this (e.g., use of specific construction materials or cladding to reduce visual impact, provision of a visitor centre).

During the planning phase, storage issues closely link to the other EURAD roadmap domains of inventory (2.1.1), waste acceptance criteria (2.1.2) and technology selection (2.1.3).

3.2 Programme Implementation

In implementing a storage programme, facilities need to be constructed and commissioned to demonstrate that they are performing as expected. A safety case needs to be produced, showing how the facility addresses the design requirements and external factors identified in Section 3.1. Records of the design and as-built facility need to be kept, supporting future longevity assessments, including material specifications. Coupons[3] of construction materials can be installed to support monitoring of structural elements.

Suitably qualified and experienced persons (SQEP) need to be appointed to manage and operate the store, with training and succession planning to enable staffing of the facility over long periods.

Before any waste, material or spent fuel can be emplaced in the store, waste acceptance criteria (WAC) should be established. WAC include conditioning and packaging requirements for import to the store, handling and emplacement infrastructure, and subsequent retrieval and disposal requirements. The following criteria need to be established and potentially iterated throughout the lifetime of store operations:

- the types of waste packages and/or transport containers that can be accepted;
- how the packages will be inspected on receipt and shown to meet the WAC;
- how the packages will be moved and arranged within the store, considering shielding, criticality prevention, or cooling requirements as applicable;
- monitoring requirements; and
- the security category of the material being stored.

The store environment needs to be maintained to ensure that the suitability for disposal of the waste packages is not impaired. This is usually achieved by regulating temperature and/or relative humidity to prevent corrosion of the container materials. Environmental controls can be installed (e.g., passive or active ventilation), as well as fire alarms and hydrogen alarms if gas generation is a risk.

For pond storage of spent fuel, monitoring of the pondwater is required to detect any changes in pond depth, water chemistry, increased concentrations of radionuclides that could indicate leakages, evidence of unexpected fuel degradation, or the need to top up additive chemicals. .

Records management systems need to be established to store package-specific information provided by the donor facility, inspection data gathered during package receipt and ongoing monitoring activities, the location of the package within the store and any additional data needed to demonstrate compliance with disposal facility WAC.

Regulatory engagement is needed to establish confidence that appropriate arrangements are in place for the safe and secure storage of RW, materials or spent fuel.

During the implementation phase, storage issues closely link with the other EURAD roadmap domains of treatment and processing (2.2.2), conditioning (2.2.3) and, if the store is not co-located with the waste or spent fuel, transport (2.2.5).

3.3 Programme Operation and Closure

[3] Coupons are typically made from the same materials as the system being monitored and are placed within the system to be exposed to the same environment. They can be withdrawn and characterised to provide a representative assessment of the integrity of the whole structure.

In most countries, RW and spent fuel are being managed by their producers with a nominal storage life of 50 years. Countries such as Belgium, Finland, Sweden and Switzerland explicitly state that extended storage is not considered in their national strategies. In other countries, including the Netherlands, Spain and the United Kingdom, longer storage periods (up to 100 years) have been implemented, in some cases using centralised storage facilities [NEA, 2020].

During operation of the storage facilities, there will be an ongoing need to operate the facility and equipment, including periodic monitoring of the store structure, environmental conditions and waste packages for quality assurance (QA) or safeguards, and to ensure that the packages are maintained in a retrievable and disposable condition during the storage period.

Due to the expected long lifetimes of storage facilities, asset management will berequired, including identification of life-limiting features and planned maintenance, refurbishment and replacement activities. The long period of operation may also lead to knowledge management issues, including the availability of SQEP staff to operate the plant, especially at the time of package retrieval if it occurs after a long period of storage, and ensuring the maintenance of a records management system.

The store needs to operate according to the applicable regulatory requirements, which will involve management of secondary waste, gaseous and liquid effluents, if any, generated during the storage period.

Regulatory engagement will continue to ensure that the store operations meet their requirements, including for SQEP staff and knowledge management, and that monitoring results indicate that the store is being well maintained and waste packages are in good condition. The level of intervention will vary depending on the nature of the storage facility. For example, pond stores and those with active ventilation systems will require more monitoring, intervention and maintenance than dry stores with passive ventilation and passive environmental control systems.

Prior to store closure, plans for store emptying will need to be updated. Retrieval of packages will be closely tied to the availability of a near-surface disposal facility or DGR (as appropriate), or the construction of a replacement store, depending on the strategy in place at the time. Waste packages will then need to be retrieved from the store and placed within transport packages (if needed) for onward transport. Remedial work may be needed for any packages damaged during the storage period at a rework or overpacking facility within or adjacent to the store.

Finally, once emptied, the store structure and equipment will need to be decommissioned and all waste generated managed according to the waste hierarchy.

During the operations phase, storage issues closely link to the other EURAD roadmap domains of quality & management systems (2.3.1) and optimisation (2.3.2).

During the closure phase, storage considerations are closely linked to the other EURAD roadmap domains of transport (2.2.5) and waste acceptance criteria (2.1.2), in terms of demonstrating that, following the storage period, the retrieved waste is suitable for transport (in a transport container if needed) and acceptance at the relevant endpoint.

During decommissioning of the stores, secondary waste management (2.3.3) also needs to be considered.

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

The critical issues for storage are summarised by the regulatory objectives [WENRA, 2014; IAEA, 2018]:

- Safety management, organisation and records.
- Design.
- Operation, including arrangements for waste package receipt, inspection and maintenance, contingency planning, and retrieval of waste packages at the end of the storage period.
- Security and safeguards.
- Safety verification, including development and updating of a safety case for the storage facility and its contents during the lifetime.

Due to the expected long lifetimes of storage facilities, asset management is required, including identification of life-limiting features, considering the need for planned refurbishment and replacement. Depending on the type of store, typical life-limiting features may include the store structure itself and crane rails or other components of package handling equipment within the active area. Obsolescence of components and infrastructure (e.g., control systems, package handling equipment) is a significant issue that may be addressed by stock-piling replacement parts during construction.

Knowledge management systems are critical enablers for the continued operation and maintenance of the store over long time periods and retrieval of waste at the end of the storage period. The long period of operation and discontinuous nature of some activities (such as package handling) may lead to a lack of availability of staff with appropriate skills, knowledge and experience. Training, organisational learning and knowledge capture are be needed to ensure SQEP staff are in place. Record management systems have to be maintained for waste packages, environment, store equipment and store maintenance. These records are required to demonstrate disposability or suitability for further management of retrieved waste packages.

The primary responsibility for safe storage rests with the store operator, who therefore needs to ensure that they have a good understanding of the waste, material or spent fuel received so that it can be managed safely. This includes ensuring the continuing robustness of the relevant safety cases, including those for containment, appropriate shielding, criticality safety and heat management if applicable.

5 MATURITY OF KNOWLEDGE AND TECHNOLOGY

Storage of RW is a mature topic with a track record of providing safe and secure containment for over 50 years. As a result, some MS consider that further R&D in this area is not required. This is particularly the case for storage of contact-handled

RW and spent fuel in dry cask storage in existing facilities with established safety cases and monitoring procedures based on visual inspection.

However, it may be necessary to develop remote monitoring and inspection methodologies, and digital twins for HLW, nuclear materials and spent fuel where access to the materials is significantly more challenging. In the case of legacy facilities, confidence may need to be developed that the waste packages and/or store will remain in good condition and continue to operate beyond their original design life.

This section identifies the latest developments, including innovations at lower levels of technology maturity where ongoing RD&D and industrialisation activities continue to improve.

Advances in waste storage issues

New technologies related to storage that are being implemented or could be applicable to the RW domain include:

- the use of robotics and remote sensing technologies for package monitoring, which can significantly reduce human exposure and improve confidence in the store system performance,
- the use of non-destructive evaluation (NDE) techniques to assess package integrity,
- the use of sensing technologies that employ wireless power supply for functioning and data transmission, development of digital twins for both the store and the waste packages, including application of machine-learning algorithms that can offer early information on waste package evolution and inform decision making,
- development of data handling protocols and decision framework models that help operators use gathered data to make decisions on waste package storage and handling,
- the storage of interim products that are expected or have the potential to form part of a future disposal solution following the interim storage period,
- the use of decay storage management for short-lived intermediate level waste (SL-ILW) to enable diversion of waste from geological to near-surface disposal facilities,
- the use of long-term storage as a management option for disused sealed radioactive sources, and
- new types of dual-use casks that can be used for both transport and storage.

Optimisation challenge and innovations

Ongoing activities within Work Package 7 of the EC PREDIS project (2020-2024) are focused on cemented waste handling and pre-disposal storage, including use of monitoring technologies and digital twins to demonstrate store and package quality assurance.

Package movements within stores can potentially result in accidents, damage to packages, dose to operators and disruption to package receipt operations. Therefore, it is of significant benefit to implement *in-situ* monitoring of waste packages using remote-operated cameras and the inclusion of dummy or mock-up packages in stores equipped with internal RFID (radio frequency identification) sensors to measure temperature, humidity and pressure, as well as strain gauges, fibre-optic sensors and acoustic emission sensors on the drum exteriors. These lead to improved confidence in waste package evolution and performance and, if inactive, can be retrieved periodically for further testing without shielding and containment requirements.

The following work packages of EURAD (2019-2024) are specifically addressing waste storage issues:

- The waste management routes in Europe from cradle to grave (ROUTES) project is sharing experience and knowledge on RWM routes between WMOs, TSOs and REs from different MS, with a particular focus on challenging wastes and developing shared solutions. Storage is considered as a high priority [EURAD ROUTES website].
- The spent fuel characterisation and evolution until disposal (SFC) project is developing characterisation techniques that will allow us to better understand the physiochemical evolution of irradiated spent fuels (pellets and cladding) under normal and credible accident scenarios following reactor discharge (i.e., during interim storage (wet and dry), transport to and emplacement in a DGR) [EURAD SFC website].
- The interaction with the civil society work package recognises that the successful implementation of RWM national programmes relies on both scientific and technical aspects for a sound safety strategy and scientific and engineering excellence and societal (social, legal, ethical, political) aspects. Therefore, involvement of civil society organisations (CSOs) is important to improve the mutual understanding on RD&D performed to support the development of safe solutions of processing and disposal of RW [EURAD Interaction with Civil Society website].

6 PAST RD&D PROJECTS ON STORAGE

As noted above, storage of RW and spent fuel is a mature topic. Past IAEA and/or European Commission funded projects have addressed storage of RW, materials or spent fuel and produced guidance and good practice reports. These have included:

- IAEA Technical Report on Interim Storage that summarised safety requirements and outlined types of storage facilities and operational good practice, TRS-390 [IAEA, 1998].
- IAEA Coordinated Research Project: Behaviours of cementitious materials in long term storage and disposal of radioactive waste, TECDOC 1701 [IAEA, 2013].

NEA, through the Radioactive Waste Management Committee (RWMC) and associated sub-committees also support members in developing safe and economically efficient management of all types of RW including spent fuel, based on the latest scientific and technological knowledge. This includes consideration of storage aspects [NEA, 2020].

Individual MS have also conducted research, development and demonstration (RD&D) and developed guidance on best practice for storage of RW and spent fuel, including the UK's Nuclear Decommissioning Authority Integrated Project on Storage [NDA, 2021] and the French Centre National de la Recherche Scientifique (CNRS) Radioprotection guidance, which includes storage of RW and effluents [CNRS, 2018].

7 UNCERTAINTIES

Storage of RW and spent fuel practices are advanced with minimal uncertainties. Existing implementation guidance, for instance from the IAEA, NEA and national regulatory bodies, provide good practice and advice for those developing storage policies or constructing and operating storage facilities.

Evolution of stakeholder requirements, including the WAC for disposal facilities, during the storage period is a significant uncertainty that cannot be addressed by RD&D. However, the risk that packages are no longer disposable after storage can in part be mitigated by maintaining knowledge management systems to ensure good records are held for the waste packages in storage and ongoing monitoring programmes to give confidence that package performance continues to meet current requirements. Remaining uncertainties that could be addressed by RD&D include:

- Improved understanding of expected waste package evolution during storage, including the understanding of corrosion, gas generation and other physical and chemical properties over time. This understanding can be used to support arguments that the stored packages can be directly disposed of without overpacking.
- Development of multi-purpose waste packages that can be used for transport, storage and disposal, noting that aging management programmes would be required to ensure continued transportability of packages following interim storage.
- Development of new digital and remote monitoring of packages and store building infrastructure to provide QA and reassurance that the storage system is behaving as expected.
- Development of remote package and infrastructure monitoring techniques to support extension of the operational lifespan of interim storage facilities. Package monitoring may involve the use of remote activity mapping (e.g., detect localised hotspots), laser profiling techniques (e.g., to confirm or monitor dimensional parameters), and where seals are present monitoring their performance and internal pressure. Approaches to package monitoring might also involve the development and application of statistically based sampling regimes to ensure adequate coverage of the package population and to help define sampling frequencies [PREDIS, 2023].
- Development of approaches for package remediation following interim storage, including damaged waste packages, those used to store raw waste and those which do not meet the WAC for disposal. RD&D may involve development of techniques for package repair or reinstatement (e.g., over-packing, application of repair grouts and/or the application of surface coatings) [PREDIS, 2023].
- Understanding the potential for long-term storage as a management option for disused sealed radioactive sources, noting that this is not an option in some countries (e.g., Switzerland).
- Improved understanding of the impacts of extended storage (beyond 100 years) on waste package performance, including potential for decay storage to enable re-categorisation and diversion of waste to alternative routes [PREDIS, 2023].
- Understanding of expected store infrastructure evolution and methods to extend the operating period of the store beyond its design life, including use of lessons learned from other industries relating to aging management

of bridges and other concrete structures, [Beunfeld et al, 2008], as well as nuclear-specific asset management experience [IAEA, 1990].

8 GUIDANCE, TRAINING AND COMMUNITIES OF PRACTICE

This section provides links to resources, organisations and networks that can help connect people with people, focused on the domain of storage.

Guidance
• IAEA (1998), Interim Storage of Radioactive Waste Packages, Technical Reports Series No.390, online • NEA Nuclear Energy Agency (2020), Storage of radioactive waste and spent fuel, NEA Report no. 7406, online • UK Nuclear Decommissioning Authority (2021), Industry Guidance: Interim Storage of Higher Activity Waste Packages – Integrated Approach, Issue 4, online
Training
• IAEA Spent Nuclear Fuel Storage training course available in Learning Management System: https://elearning.iaea.org/m2/course/index.php?categoryid=60 • Storage topics covered in EURAD training course on RWM: https://euradschool.eu/event/training-course-on-radioactive-waste-management/
Active communities of practice and networks
• The WENRA Working group on waste and decommissioning (WGWD) addresses the regulatory aspects relating to RW, spent fuel and decommissioning matters, including storage: https://www.wenra.eu/wgwd. • The NEA Expert Group on the Economics of Extended Storage of Spent Nuclear Fuel (EGEES) is gathering and appraising available knowledge from member countries to identify and assess the impact of technical, safety and regulatory, economic and social factors related to different storage options, fuel types and technical conditions: https://www.oecd-nea.org/jcms/pl_29109/expert-group-on-the-economics-of-extended-storage-of-spent-nuclear-fuel-egees. • IAEA International Predisposal Network (IPN) is a forum for the sharing of practical experience and international developments on RWM activities before disposal: https://nucleus.iaea.org/sites/connect/IPNpublic/SitePages/Home.aspx) • In the UK, the Store Operations Forum (SOF) brings together Nuclear Decommissioning Authority (NDA) strategic leads, Nuclear Waste Services (NWS), waste producers and store operators to engage, coordinate and drive strategy development through shared learning [NDA, 2021].

Key competences that are needed in the area of RW storage include store and waste package design, shielding, criticality safety and thermal modelling expertise, material and corrosion science for package integrity, logistics, radiological measurements and monitoring, knowledge management, data handling and preservation, risk management and safety case development, communication (stakeholder engagement), programme management.

9 ADDITIONAL REFERENCES AND FUTURE READING

Beunfeld, N.R., Davies, R.D., Karimi, A. and Gilbertson, A.L. (2008), Intelligent Monitoring of Concrete Structures, DTI report no. CIRIA C661, sold online

EU (2011), Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, online

EU (2005), Safeguarding Nuclear Materials, Summary of Regulation (Euratom) No 302/2005 on the application of Euratom safeguards, online

IAEA (1990), Safety Aspects of Nuclear Power Plant Ageing, TECDOC 540, online

IAEA (1998), Interim Storage of Radioactive Waste Packages, Technical Report Series No.390, online

IAEA (2007), Safety Glossary: Terminology Used in Nuclear Safety and Radiation Protection, online

IAEA (2009), Predisposal Management of Radioactive Waste, General Safety Requirements, No GSR Part 5, online

IAEA (2013), The Behaviours of Cementitious Materials in Long Term Storage and Disposal of Radioactive Waste, TECDOC 1701, online.

IAEA (2018), International Safeguards in the Design of Facilities for Long Term Spent Fuel Management, No NF-T-3.1, online

IAEA (2019), The Management System for the Predisposal Management and Disposal of Radioactive Waste, DRAFT SAFETY GUIDE DS477, online

IAEA (2021) Report of the integrated review service for radioactive waste and spent fuel management, decommissioning and remediation (ARTEMIS) Mission to Ireland, online

Ministry of Infrastructure and the Environment (2016), The national programme for the management of radioactive waste and spent fuel, The Netherlands, June 2016, online.

Nagra (2016), Waste Management Programme 2016 of the Waste Producers, Technical Report 16-01E, online

NEA (2020), Storage of Radioactive Waste and Spent Fuel, NEA Report no. 7406, online

ONDRAF-NIRAS (2022), Storage Facilities for (Non) Conditioned Low and Medium-Level Waste on the Territory of Dessel (Belgium), online

PREDIS (2023), Milestone 2.4: Strategic Research Agenda, Version 2, online

SOGIN (2023), National Repository and Technology Park, online

Swiss Federal Council (2004), Nuclear Energy Ordinance (NEO) Chapter 2, Article 12 Design Principles for other nuclear installations, online

UK Nuclear Decommissioning Authority (2021), Industry Guidance : Interim Storage of Higher Activity Waste Packages – Integrated Approach, Issue 4, online

Western European Nuclear Regulators Association (2014), Report: Waste and Spent Fuel Storage Safety Reference Levels, Version 2.2, online