Milestone 60: Workshop on alternative RWM strategies for long-term storage exceeding the design lifetime

Work Package 3 ASTRA

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Executive Summary

This report presents the outcomes of ASTRA WP Subtask 3.2 and constitutes Milestone 60, synthesising the second stage of the Task 3 analysis on radioactive waste storage facilities and waste packages that have exceeded, or are expected to exceed, their design lifetime across Europe. Drawing on technical and strategic information collected from 22 organisations in 15 countries, including Waste Management Organisations (WMOs), Technical Support Organisations (TSOs), Research Entities (REs), and Civil Society Organisations (CSOs), the report builds on the findings reported in Milestone 38.

While Milestone 38 established the initial baseline by mapping facility numbers, broad reasons for extended storage, ageing management practices, data preservation issues and transparency aspects, Milestone 60 focuses on a more detailed facility-level assessment. It analyses the reported characteristics of storage facilities and waste packages, waste types and storage methods, service life of packages, safety reassessment results, main risks and vulnerabilities, urgency of retrieval, future management strategies, cost estimations and funding sources.

The analysis confirms that extended storage is not a uniform situation across Europe. In some countries, facilities operate within periodic safety review, relicensing or licence renewal frameworks rather than fixed design lifetime limits. In other cases, legacy storage facilities or waste packages have already exceeded, or are approaching, their intended lifetime and may require retrieval, repackaging, reconditioning, relocation or preparation for disposal. Key challenges identified include ageing of engineered barriers, degradation of waste packages, incomplete or uncertain historical inventory data, limited access for inspection, capacity constraints, and dependence on delayed disposal routes.

The second Task 3 workshop complemented the survey analysis by identifying priority R&D needs. The discussions highlighted the need for clearer lifetime definitions and decision points, practical ageing management tools, predictive and probabilistic models, technical solutions for barrier strengthening, approaches to address evolving Waste Acceptance Criteria, early assessment of emerging waste streams, and stronger integration of societal aspects such as transparency, trust and intergenerational responsibility.

Keywords

Alternative RWM strategies, SIMS, LIMS, storage facilities, design lifetime, ageing management, data quality, knowledge transfer, transparency & public participation, international cooperation, ASTRA WP, EURAD-2

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List of Acronyms

ASTRA WP: Work Package "Alternatives RWM strategies" in EURAD-2 partnership

CSO: Civil Society Organisations

EURAD-2: European Partnership on Radioactive Waste Management

LIMS: Large Inventory Member States

R&D: Research and development

RE: Research Entity

RWM: Radioactive Waste Management

SIMS: Small Inventory Member States

TSO: Technical Support Organisation

WMO: Waste Management Organisation

WP: Work Package

1. Introduction

Storage remains an essential element of radioactive waste management [1]-[3]. Depending on the waste type, national programme and stage of the management route, storage may serve different purposes: it may provide time for radioactive decay and heat reduction, allow for further treatment or conditioning, or act as an interim step before disposal. In set of national programmes, however, storage periods have become longer than originally anticipated. This is often linked to delays in the availability of disposal facilities, evolving national strategies, technical and financial constraints, as well as political, institutional and societal factors that influence the implementation of long-term radioactive waste management solutions.

The extension of storage periods, and in some cases the operation of storage facilities or waste packages beyond their original design lifetime, may create a set of safety, technical, regulatory and organisational challenges [4]. Continued storage shall remain safe, controlled and justified over time, this requires not only the physical integrity of storage facilities and packages, but also reliable information on waste inventories, ageing mechanisms, inspection and monitoring results, safety reassessments, retrievability options, and the availability of realistic future management routes.

European Partnership on Radioactive Waste Management (EURAD-2) [5] creates a platform of collaborative effort among Member States and brings the opportunities to develop, maintain and consolidate the scientific and technical basis of radioactive waste management [6]. Within EURAD-2, Work Package (WP) 3 ASTRA addresses the readiness, feasibility and challenges of alternative radioactive waste management solutions needed in national programmes [7]. Task 3 of ASTRA WP was established to examine situations where radioactive waste is stored for periods exceeding, or expected to exceed, the design lifetime of storage facilities and/or waste packages. The task brings together organisations from both Small Inventory Member States (SIMS) and Large Inventory Member States (LIMS) [8], reflecting the fact that extended storage is a common issue, although its scale, drivers and practical implications could differ between countries.

Task 3 has been implemented through two complementary subtasks. Subtask 3.1 focused on collecting information and developing a shared understanding of the current situation regarding radioactive waste storage facilities and packages with exceeded or extended design lifetimes. The results of this first stage were presented in Milestone 38 [4]. That report was based on a structured survey involving 22 organisations from 15 countries and on the discussions held during the first Task 3 workshop, which brought together 33 participants from 17 countries, representing Waste Management Organisations (WMOs), Research Entities (REs), Technical Support Organisations (TSOs) and Civil Society Organisations (CSOs).

Milestone 38 [4] provided the initial analytical basis for Task 3. It described the general number and status of radioactive waste storage facilities reported by participating countries, identified facilities operating beyond their design lifetimes, and summarised the main reasons for such situations. It also discussed key technical and regulatory challenges, environmental hazards, ageing management measures, the quality and accessibility of radioactive waste data, approaches to long-term preservation of records and knowledge transfer, as well as practices related to transparency, public involvement and international cooperation. In this way, Milestone 38 [4] established the broader context and highlighted the main issues that require further technical and strategic consideration.

The present report, Milestone 60, builds directly on the findings of Milestone 38 [4] and represents the second step of the Task 3 analysis. While Milestone 38 focused mainly on the overall situation, common challenges and supporting conditions for continued safe storage, this report examines the second part of the collected data in greater detail. It provides a more focused analysis of the storage facilities and waste packages concerned, including the characteristics of the stored radioactive waste, applied storage methods, expected or actual service lives of waste packages, and the available information from safety reassessments.

In addition, Milestone 60 addresses the risks, uncertainties and hazards associated with extended storage, as well as the urgency of waste retrieval where relevant. Particular attention is given to future strategies and planned or implemented approaches for managing storage facilities and packages with exceeded or extended design lifetimes. This includes consideration of possible timeframes, cost estimations, funding sources and decision-making factors. The report also reflects the outcomes of the second Task 3 workshop, which focused on discussing priority needs for further research and identifying areas where joint work, knowledge exchange and international cooperation could provide practical added value.

Taken together, Milestone 38 [4] and Milestone 60 provide a complementary picture of the issue. Milestone 38 [4] set out the current landscape, common challenges and cross-cutting needs, while Milestone 60 deepens the analysis by focusing on technical details, safety reassessment, retrieval considerations, future strategies and research priorities. This combined work is intended to support the development of a better shared understanding of how radioactive waste storage beyond design lifetime is managed in practice, and what further actions may be needed to ensure safe, informed and sustainable decision-making in this area.

2. Data collection

2.1 Questionnaire

The data used for Task 3 were collected through a dedicated questionnaire developed as the main instrument for gathering information on radioactive waste storage facilities and waste packages whose design lifetime has been exceeded, extended, or may need to be extended in the future. The questionnaire was intended to provide a common factual basis for the analysis of national practices, technical challenges, safety considerations and possible future management strategies. A detailed description of the questionnaire structure, its development and the full list of questions is provided in Milestone 38 [4].

The questionnaire covered both facility-level information and broader institutional, regulatory and societal aspects. It was structured around six main areas:

- general information on the respondent and national storage situation;
- status of radioactive waste storage facilities and packages;
- challenges, ageing management and risk assessment;
- future strategies and possible management routes;
- public involvement and transparency;
- opportunities for international cooperation and knowledge exchange.

This structure made it possible to collect not only technical data on storage facilities, waste characteristics, package service life and safety reassessment, but also information on data management, record preservation, decision-making processes, funding arrangements and stakeholder engagement.

The questionnaire was first discussed with Task 3 participants during the Task 3 Kick-off meeting. Feedback received at this stage was used to refine the questions and ensure that the survey reflected the range of interests and responsibilities represented in the task, including WMOs, REs, TSOs and CSOs. Additional focused exchanges were also held with civil society representatives, in order to ensure that issues related to transparency, public information and stakeholder confidence were adequately reflected. Following this consultation process, the final questionnaire was made available through the EUSurvey platform.

2.2 Survey

The survey was completed by 22 organisations from 15 countries: : Austria (NES, NTW), Bulgaria (TUS, NTW), Czech Republic (SURO), Denmark (DEKOM, NTW), Estonia (UTARTU), Finland (VTT), France (ASNR, NTW), Germany (DMT), Greece (NCSRD), Netherlands (NRG, COVRA), Poland (ICHTJ), Portugal (IST-ID), Slovenia (EIMV), Switzerland (PSI, ZWILAG), and Ukraine (SSTC NRS, ENERGORISK). Respondents were invited to provide detailed answers where possible, while also indicating cases where information was unavailable or not applicable. This approach was important for identifying not only existing practices and available data, but also gaps in knowledge, accessibility and documentation. By involving various organisations from the same country, the survey successfully underscored how interpretations, priorities, and open-access information availability can vary significantly between different actors within a single national framework.

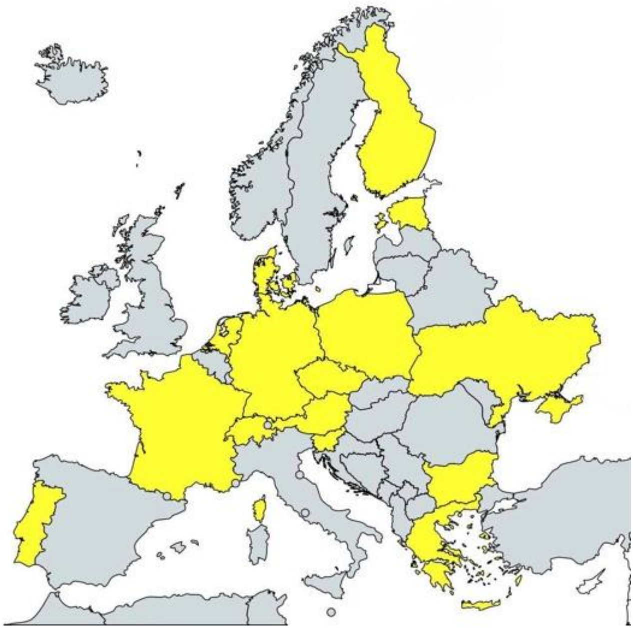

Figure 1. Map with countries that took part in the survey

Figure 2. Distribution of organisations that took part in the survey by type

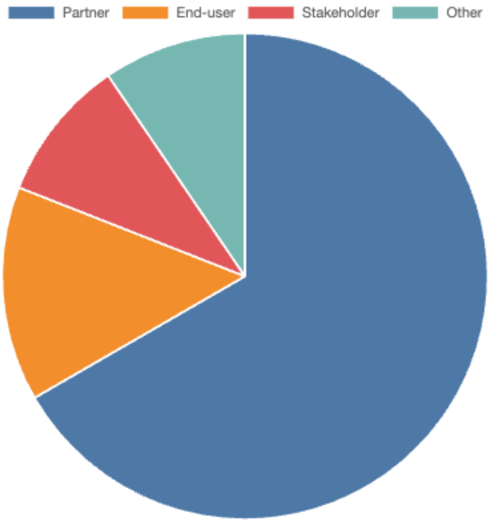

Figure 3. Distribution of organisations that took part in the survey by role in Task 3 of ASTRA WP

The collected responses were stored and made available to ASTRA WP partners through the EURAD-2 ProjectPlace. The survey results were then organised and analysed by thematic groups of questions and, where relevant, by country, allowing both common trends and country-specific circumstances to be identified. The overall survey process and the first part of the analysis are described in detail in Milestone 38 [4].

2.3 Scope of the analysis in Milestone 60

Milestone 38 [4] presented the first stage of the ASTRA WP Task 3 analysis. It focused mainly on the general overview of radioactive waste storage facilities, the identification of facilities operating beyond their design lifetimes, the main reasons for lifetime exceedance or extension, general ageing management challenges, data quality and accessibility, record preservation and knowledge transfer, public involvement, transparency, and opportunities for international cooperation. It also reflected the discussions held during the first Task 3 workshop.

The present report, Milestone 60, builds on that work and focuses on the second part of the survey data, which is more technical, safety-oriented and forward-looking. In particular, it analyses the detailed information provided on the storage facilities concerned, including their designed operational lifetime, expected end of operation, applied storage methods, characteristics of the stored radioactive waste, and expected service life of waste packages. Where available, the analysis also considers information on waste classification, volumes, radiological characteristics and physicochemical properties.

A second major focus of this report is the safety reassessment of facilities and packages operating under extended storage conditions. While Milestone 38 [4] addressed the broader challenges associated with ageing and continued storage, Milestone 60 examines more specific information on facility resistance to natural and human-induced hazards, radiation-related impacts, identified risks and uncertainties, and the urgency of waste retrieval or other remediation actions. This part of the analysis is intended to provide a clearer understanding of how safety is reassessed in practice when storage facilities or packages remain in operation beyond their original design assumptions.

Finally, Milestone 60 considers the future strategies and management approaches reported by participating Member States. This includes planned or already implemented measures such as lifetime extension, continued storage under enhanced controls, retrieval and repackaging, relocation of waste, facility upgrading, or closure. Where available, the report also examines the timeframes associated with these strategies, the availability of cost estimations, and the funding sources expected to support their implementation. In this way, Milestone 60 complements Milestone 38 [4] by moving from the general mapping of the issue towards a more detailed assessment of technical conditions, safety reassessment, retrieval needs, future management options and priority areas for further work under Subtask 3.2.

Below, in Section 3, are the main results corresponding to the survey topics included in this report.

2.4 Main findings

2.4.1 Status of RW storage facilities

The responses show a broad diversity of radioactive waste storage situations across the participating countries. The facilities reported include interim storage facilities, legacy waste storages, storage halls, waste repositories used for storage or disposal-related purposes, storage facilities for spent fuel or high-level waste, storage facilities for institutional radioactive waste, and facilities containing disused sealed radioactive sources or historical waste. It is important to note that in several countries, spent nuclear fuel (SNF) is classified as radioactive waste.

A recurring feature is that not all facilities have a clearly defined design lifetime or end date. In several cases, respondents indicated that the original facility design did not specify a formal end-of-life date, especially for older or legacy facilities. Other responses provided specific operational periods or expected end dates, including years such as 2039, 2040, 2043, 2046, 2065 and 2074, while some facilities were reported as having no established end of operation.

The answers also show that the concept of "design lifetime" is interpreted differently depending on the national and facility context. In some cases, it refers to the design lifetime of the storage building; in others, to the operational licence, planned closure date, service period of waste packages, or expected availability of a future disposal or relocation route.

2.4.2 Description of facilities by country

The reported facilities include, among others, the following types of facilities and storage situations:

- central or national interim storage facilities;
- storage facilities at NPP sites;
- storage facilities for institutional and research waste;
- storage facilities for spent fuel and high-level waste;
- legacy waste storage or disposal sites;
- storage facilities for disused sealed radioactive sources (DSRS);
- storage facilities undergoing reconditioning, retrieval or preparation for future closure;
- grouped national or site-level RWM facilities.

The following country profiles provide an overview of national approaches to RWM, with a particular focus on storage facilities and waste packages that have exceeded, or may approach, their original design lifetime. The information summarises the reported status of storage facilities, waste types and storage methods, key safety risks and vulnerabilities, ageing management measures, data availability and inventory quality, as well as planned or implemented strategies for lifetime extension, retrieval, reconditioning, disposal or closure. The country-specific summaries also reflect differences in the level of detail, accessibility and openness of information, including aspects related to transparency, public involvement and international cooperation.

2.4.2.1 AUSTRIA

Two organisations participated in the survey: NES (WMO) and NTW (CSO).

In Austria, four temporary RW storage facilities operate at one site.

I. According to NES, one of them, the LH12 facility, is recognised as not complying with modern requirements for safe storage and the WAC in force at the time of analysis. In the country, no design operational lifetime for storage facilities is documented; the regulatory body carries out annual control of the technical condition and safety level of each facility.

As of the end of 2024, LILW-SL and LILW-LL are stored in the LH12 facility, packaged in conditioned 200-litre drums. Due to identified signs of package corrosion, the presence of free liquid, combustible materials, voids and other non-compliant contents, a reconditioning project was initiated, including opening of drums, sampling, updating of information on the chemical and radiological characteristics of the waste, and reprocessing, including supercompaction.

To extend safe storage until the construction and commissioning of the final repository is completed, planned after 2045, waste from the LH12 facility is being transferred to new temporary storage facilities with controlled microclimate, enhanced seismic protection and the possibility of individual monitoring of each package unit at least once every 5 years. These facilities have undergone a comprehensive safety assessment, including analysis of the impact of potential natural and anthropogenic hazards, as well as a hypothetical accident involving an aircraft crash followed by fire. Radiation exposure in such an incident is assessed as very insignificant, owing to engineering barriers and design solutions.

II. According to NTW, the identified temporary NES storage facility in Seibersdorf has been operating since the early 1970s. Official information on the design operational lifetime of this facility is not publicly available, but it is assumed that its operational lifetime already exceeds 50 years. According to an agreement with the local community, operation of the facility must end by 2045; however, such long-term operation may create both technical and social challenges for ensuring safe storage during the beyond-design period. The main factors that influenced the extension of the storage facility lifetime are the absence of a geological repository, limited funding and postponement of specific decisions. To revise the period of further operation of the storage facility after 2045, public approval of such a decision is required based on an environmental impact assessment.

The facility stores small volumes of LLW/LILW-SL and ILW/LILW-LL placed in primary packages, containers, wells, etc. Information on the service life of RW packages is not public. NTW does not have public access to the results of safety reassessment, except for information on the calculated aircraft crash scenario for the storage facility, for which the maximum public dose is estimated at 20 microSv in the first year, nor to the service life of packages, and has limited access to technical information. However, it is noted that measures are being implemented for RW repackaging and conditioning, reconstruction of the storage facility and improvement of the data preservation system.

Both organisations identify problems with the verification of old records, in particular due to loss of documentation and changes in accounting formats since the 1970s.

2.4.2.2 BULGARIA

Two organisations participated in the survey: TUS (RE) and NTW (CSO)

The data provided by TUS reflect a technical analysis carried out with minimal public access to current data. NTW represents the civil society perspective, which emphasises the complete absence of transparency, monitoring, public participation, safety information and strategic management.

According to the responses provided by NTW, Bulgaria has at least five known RW and SNF storage facilities, some of which have been in operation for a long time, while official information on their technical lifetime, operating conditions and condition assessment is limited or absent.

These facilities include the Novi Han storage facility near Sofia, two specialised SERAW RAW-Kozloduy sites, and two SNF storage facilities at Kozloduy NPP. Another facility is under construction at the Radiana site next to Kozloduy NPP: a near-surface trench-type National Repository for LLW/ILW.

The responses provided by TUS mention three main RW storage facilities, at least one of which could potentially exceed its design service life, although official information on this is absent. Detailed characteristics of individual facilities are not provided, but it is indicated that storage methods include storage in primary packages, containers, wells for DSRS, etc. The risk level for this storage facility is also indicated as medium.

TUS and NTW emphasise the absence of up-to-date, complete and structured information on the actual technical condition of RW storage facilities. Data on RW volumes, activity, physicochemical characteristics, the presence of safety barriers, free storage capacity or monitoring results are absent or outdated. Even general indicators regarding facility operational lifetimes are not published. There is no documented information on safety reassessments of storage facilities after reaching or approaching design service lifetimes. Ageing Management Plans (AMPs), including monitoring of protective systems, packages and load-bearing structures, are either not implemented or not envisaged. At the same time, the possible existence of potential risks is considered, related to degradation of RW packages, reduced resistance to climatic impacts, erosion of barriers and increased environmental impact; however, public information on accident analysis scenarios, assessment of long-term environmental impacts or ranking of storage facilities by radiological risks is also absent.

2.4.2.3 CZECH REPUBLIC

One organisation participated in the survey: SURO (TSO)

Four RW storage facilities operate in the Czech Republic, located at the sites of NPP Dukovany (EDU), NPP Temelín (ETE), ÚJV Řež, a. s. (Velké zbytky storage facility) and separate premises in the RICHARD near-surface disposal facility (SÚRAO). These facilities apply integrated storage technologies for liquid RW, solid RW and DSRS using sorption units, drums, well-type storage facilities and protective containers.

The RICHARD repository also has separate rooms for DSRS that do not meet acceptance criteria for final disposal, with additional requirements for tightness, suitability for handling and compliance with the design service life of packages. The design operational lifetime of most facilities is 50–60 years, corresponding to the expected operating period of NPPs in the country. No exceedance of the design operational lifetime of RW storage facilities or packages has been recorded.

It is planned that all waste, after decommissioning of NPPs, will be transferred to a deep geological repository. If the creation of such a repository is delayed, construction of a new facility or reconstruction of an existing one is envisaged. Information on RW inventories is complete, up to date and continuously updated.

The level of accounting and control of radioactive waste in the Czech Republic is assessed as high. Regulatory conditions, including licences and technical operational limits, clearly define data parameters and procedures for their verification and access. No gaps or distortions in the information were identified.

Storage facilities, including containment systems (package), are always licensed as a whole. If a problem arises, corrective measures must be taken and the licence renewed. Licences are issued for a limited period of either 5 or 10 years, depending on the facility. For example, storage facilities at power plants are usually issued for 10 years. Once this period has expired, the facility's condition is periodically assessed, and the operator must apply for a new decision. Whether the permit is reissued does not depend on the minimum service life of the storage facility, its instruments or its equipment, but on its physical condition.

A similar situation applies to the waste packages themselves. The SÚJB (regulator) decision is usually time-limited. It does not exceed 10 years for decisions on package set type approval. Before the term expires, the manufacturer or user of the packaging set must apply for a new decision on the type approval of the packaging set. As the Czech Atomic Act does not permit the extension of valid decisions, applicants must submit updated documentation demonstrating that there have been no changes to the strength, shielding and leak-tightness characteristics or other properties of the packaging assemblies due to radiation, temperature and pressure stresses on the packaging set or as a result of handling the packaging set during transport and storage. This documentation must also confirm that the packaging assemblies will continue to meet the properties declared in the previously assessed documentation for the subsequent period.

Since none of the operating storage facilities has yet exceeded its design service life, no current practical challenges related to degradation of packages or barriers have been identified. An assessment of potential environmental risks is being carried out.

2.4.2.4 DENMARK

Responses were provided by two organisations: Danish Decommissioning (WMO) and NOAH Friends of the Earth Denmark/NTW (CSO).

Denmark has six RW storage facilities. Interim RW storage is considered a key RW management strategy until geological disposal becomes available, which is planned no earlier than 2073.

According to the response from Danish Decommissioning, only one facility has been identified as having exceeded its operational lifetime and operating under complex hydrogeological conditions, namely rising groundwater levels, which are the main risk factor. Taking this factor into account, the selection of a site for a new storage facility on higher ground is a priority.

It is noted that continuous monitoring of RW storage conditions is being carried out; however, the results are not currently published.

Risk assessment is based on environmental monitoring in combination with regular radiological control measures such as smear (wipe) tests and dose rate measurements, carried out in accordance with agreements with regulatory authorities. However, detailed results of these assessments and impact analyses are not currently published. The main risk factor is identified as the high groundwater level near the coastal zone, which may potentially affect the integrity of the packages. NTW notes the need for strategic planning that should take into account assessment of package degradation and ageing risks based on the results of documented, modelled probable scenarios of these processes, as well as increased transparency and public involvement.

Both organisations recognise the presence of historical gaps in RW records, especially concerning older waste batches.

Denmark currently has limited practical experience in managing storage facilities with exceeded operational lifetimes; however, over time this issue will become more relevant, taking into account a possible delay in implementation of final geological disposal.

2.4.2.5 ESTONIA

One organisation participated in the survey: UTARTU (RE)

Estonia has one centralised RW storage facility: the interim storage facility at Paldiski, whose operational lifetime is 50 years, until 2039. At the same time, the service life of RW packages is estimated at approximately 100 years, ending in the period 2097–2125. The facility is intended for storage of LLW/ILW-SL and LLW/ILW-LL, represented by both conditioned and unconditioned package forms, including concrete and metal containers, DSRS, pipelines, etc. The main challenge is the limited quality of initial RW data. Most of the waste is historical and originates from facilities of the former USSR. Initial characterisation was incomplete due to limited capabilities in the past. To minimise uncertainties, a re-characterisation programme has been implemented. The main challenges related to long-term RW storage are corrosion of RW package components and gradual degradation of structures. To address these issues, an Ageing Management Programme has been implemented, covering visual inspection and dose rate measurements every 10 years, as well as verification of compliance with acceptance criteria 3 years after emplacement. Attention is also paid to assessing container tightness, absence of cracks, chemical activity and temperature changes. Metal and concrete packages undergo lifting tests and weld strength checks. If defects are detected, containers are repaired or replaced. In 2008, a site modernisation programme was completed, including installation of ventilation, drainage systems, fire protection, monitoring and security, which reduced the impact of external factors, including climatic ones.

Current radiation impact assessments confirm compliance under both normal and accident conditions, with dose levels not exceeding 2 mSv in the worst-case scenario, for example an aircraft crash. The radiological risk is defined as low. After 2040, gradual decommissioning of the Paldiski storage facility is planned. RW will be transferred to two final disposal facilities planned in the same area: one near-surface and one at intermediate depth.

2.4.2.6 FINLAND

One organisation participated in the survey: VTT (TSO).

Finland has 23 RW storage facilities located at two main nuclear power sites: Olkiluoto NPP and Loviisa NPP. All facilities operate within valid licences; none has exceeded its design operational lifetime, and therefore procedures for extending their operational lifetime in the future are not currently being considered. Finland implements a full RW management cycle: operating disposal facilities for low- and intermediate-level RW are available at NPP sites, while for spent nuclear fuel one of the world's first deep geological repositories, ONKALO, is being implemented by Posiva. This RW management system reduces the need for long-term interim RW storage beyond design lifetimes.

RW control is carried out within a comprehensive monitoring system that includes regular data updating and automated accounting through centralised platforms, including the IAEA SRIS database. RW classification in Finland is based on IAEA recommendations and covers four main categories: VLLW, LLW, ILW and HLW, which includes, in particular, spent nuclear fuel. Depending on the type of waste, different storage methods are applied: bulk storage, primary packages, containerised storage, liquid waste storage and wells for spent radioactive sources.

According to the national inventory, none of them has exceeded its design operational lifetime. This has been made possible by the availability of licensed disposal facilities for intermediate- and low-level RW and the active construction of a geological repository for SNF, which significantly reduces the risk of the need for long-term interim storage beyond design lifetimes.

Although specific quantitative data on RW volumes were not provided, it is stated that accounting is maintained with high accuracy and without significant gaps in documentation. The containers in which RW is stored are under continuous monitoring. The expected service life of packaging systems is determined individually depending on the type of waste and storage conditions.

Potential long-term threats include possible package corrosion, degradation of barrier materials in the geological environment and the risk of information loss due to the non-standardised nature of some historical records. To minimise these risks, an ageing management programme is being implemented, which provides for regular inspections with assessment of the physicochemical properties of containers, testing of the tightness of protective barriers and a general safety reassessment every 10 years.

Finland has successful experience in extending licences for RW and SNF storage facilities by including the relevant provisions in the NPP licence extension process. For construction licence of the storage or disposal facility, EIA with public consultation is required. EIA has also been carried as part of the licencing of the NPP lifetime extension including also impact on the LILW repository. Under the national approach, all storage licences have a fixed term, and if the duration exceeds 10 or 15 years, a mandatory periodic comprehensive safety review procedure is carried out.

None of the operating facilities poses significant environmental threats: the impact of storage facilities is assessed as minimal compared with the NPPs where they are usually located.

The country demonstrates good practice, as it has a clear RW management strategy that includes the construction of the ONKALO deep geological repository, as well as continuous monitoring and licensing of all storage facilities.

2.4.2.7 FRANCE

Two organisations participated in the survey: ASNR (TSO) and NTW (CSO).

I. According to the responses provided by ASNR, France has an extensive RW management system covering both centralised storage facilities and storage facilities located at NPP sites, research institutions and industrial enterprises (such as Orano, CEA, EDF). There are currently 13 storage facilities in operation, registered as nuclear material/waste storage facilities and licensed for RW storage. In addition, a number of other facilities are operated under separate permits for temporary or localised storage.

The structure of waste storage in France is organised according to its purpose: for RW intended for already existing disposal facilities, such as CSA (for LILW-SL), temporary storage areas for conditioned RW are used to support logistics flows prior to disposal, or areas are used for storing waste that has not yet been retrieved and still requires characterization, treatment or conditioning. At the same time, for waste intended for future disposal facilities, such as Cigéo (the planned deep geological repository for ILW-LL and HLW), storage facilities operate to temporarily hold RW until an available management route is determined. This applies for instance to HLW, which must undergo a cooling and radioactive decay period lasting several decades before becoming suitable for emplacement in a geological repository, or for some ILW-LL awaiting conditioning.

Some of the main facilities for interim RW storage include the Orano La Hague complex (vitrified and compacted waste after SNF reprocessing, bituminised RW storage), CEDRA (storage facility for ILW-LL generated by CEA activities), DIADEM (storage facility for irradiating or alpha waste from decommissioning of CEA facilities) and ICEDA (facility for conditioning and storage of ILW-LL from EDF NPPs). It should be noted that, under French legislation, SNF is not classified as radioactive waste and therefore is not included in this RW management system.

Due to the specific features of the regulatory approach, the formal definition of a "storage facility with an exceeded service life" is not applied. Instead, a system of periodic safety reassessments is in place, conducted every 10 years. The legislative framework does not generally establish specific operational lifetimes for storage facilities; ageing management is carried out on the basis of current technical assessments of the condition of storage facility engineering barriers and safety analyses, as well as the results of ongoing activities. For some facilities (CEDRA and DIADEM), the creation authorization decrees specify that storage of waste packages is limited to 50 years, but this limit does not correspond to a design lifetime. An example of ageing storage facility is on the Saint-Laurent-des-Eaux site (INB No. 74), where graphite waste is stored in facilities without a given operational lifetime. The main risks associated with this facility include the possibility of flooding of part of the infrastructure, and insufficient completeness of historical records on the characteristics of some RW, which complicates its identification and management.

Comprehensive measures are applied for ageing management, including mandatory inspections with a full safety reassessment every ten years. These measures make it possible to identify signs of degradation in a timely manner and develop appropriate engineering solutions to address them.

Strategically, France is actively working on the Cigéo deep geological disposal project, which is intended for the final emplacement of long-lived RW.

France is implementing a large-scale programme for the retrieval, conditioning and repackaging of historical RW (Waste Retrieval and Conditioning – WRC). Current legislation requires all ILW-LL produced before 2015 to be packaged no later than 2030. Due to technical complexity, the regulator establishes staged five-year milestones to assess WRC progress. Prioritisation criteria are determined according to the hazard characteristics of facilities, for example: storage facilities with ageing barriers (Orano), facility vulnerability in case of earthquake or flooding (EDF/Saint-Laurent), or strategic importance for optimisation of decommissioning (CEA).

All processes related to the closure or dismantling of storage facilities, as well as the creation of new ones, are accompanied by public discussion and consultations.

Thus, France demonstrates a systematic but at the same time flexible approach to regulating the operational lifetimes of RW storage facilities, with a focus on technical feasibility, integration with disposal policy, and a flexible combination of operational and strategic control tools. The main challenges remain the technical complexity of retrieving legacy waste, ensuring package compliance with final disposal requirements, and improving the accuracy of the radiological inventory. These aspects are of key importance for maintaining long-term nuclear safety during the interim storage phase.

II. In the responses provided by NTW, it is noted that at least eight main RW storage facilities operate in France: La Hague (Orano), Saclay (INB 72), Saint-Laurent-des-Eaux (INB 74), Ecrin (INB 175, Malvési), Cires (Morvilliers), Valduc, ICEDA (EDF Bugey) and Marcoule. However, the exact number of facilities that have exceeded their design operational lifetime remains uncertain due to insufficient public information. According to NTW, this information is often fragmented, incomplete or unavailable from a single source. Although the design operational lifetimes of many storage facilities are not specified or not publicly disclosed, NTW emphasises that at least some facilities have already exceeded or are approaching the end of their service life, taking into account their actual age, package condition, loading and delays in implementing retrieval strategies. Some facilities, such as La Hague (an almost full storage facility for spent fuel and high-level waste), Saclay (INB 72, operating since 1971), Saint-Laurent-des-Eaux (INB 74, storing graphite waste since the same year), and the facility at the Marcoule site (where the first facilities were commissioned as early as 1966), may be considered as storage facilities with exceeded design operational lifetimes. Information on the service life of RW packages, their storage conditions and critical parameters, such as tightness, activity and suitability for retrieval, remains limited in the public domain.

NTW notes that although there are several inventories in France maintained by the ASN regulator and the RW management body ANDRA, discrepancies exist between them. For example, the facilities at La Rochelle and Jarrie appear in one register but are absent from another. In addition, operational lifetimes, package types, RW volumes and characteristics are not presented in a unified manner or in one place. The general terminology used in reports, for example the concept of “inventory” instead of “list of storage facilities”, may be difficult for the wider public to understand, which complicates comprehension even when data are formally open.

Among the main reasons leading to the exceedance of package or storage facility lifetimes, NTW identifies technical limitations, such as the impossibility of dismantling or repackaging, the absence of alternative infrastructure, for example the unavailability of Cigéo, and funding limitations or delays, etc. Risk assessment under these conditions is based mainly on general assumptions about probable package degradation, ageing of barriers and vulnerability of facilities to climate change, including flooding, extreme temperatures and landslides. NTW separately emphasises risks related to the human factor, including the potential threat of neglect, abandonment of a facility without institutional support, or loss of knowledge.

Despite the existence of the national PNGMDR plan, which formally defines long-term policy in the field of RW management, NTW states that, in the area of safety of facilities with exceeded operational lifetimes, there is a lack of publicly available information on risk reassessments, retrieval plans, technical documentation on packages and ageing management measures. In the field of information transparency, NTW notes the important role of local information committees, while also indicating that projects for extending the operation of storage facilities should be subject to public discussion mechanisms. Public participation in decision-making on RW storage is recognised as extremely important, and NTW emphasises that exceeding the service life of storage facilities without informing the public is unacceptable.

The NTW assessment underlines that the main challenges in the RW storage system in France include uncertainty regarding operational lifetimes for a significant number of facilities, the absence of a centralised information system with uniform data formats, the need to strengthen public participation in decision-making on continued operation and RW retrieval, and the need for a transparent, structured and adequately resourced safety assessment programme for facilities with exceeded design service life.

2.4.2.8 GERMANY

One organisation participated in the survey: DMT GmbH & Co. KG (Industry).

Germany has 57 RW storage facilities. One HLW storage facility at the NPP Neckarwestheim site was considered as an example of a storage facility that may exceed its design operational lifetime.

It is stated that the operational lifetime of the RW storage facility at NPP Neckarwestheim is 40 years, with its end expected in 2046. All waste stored at this facility is heat-generating and is mainly represented by SNF. The storage system is based on container technology using certified CASTOR models (V/19, TN24E, 440/84mvK), designed both for the storage of whole fuel assemblies and for waste generated after SNF reprocessing. The design service life of the containers is 40 years; the first of them will reach the limit of their service life in the late 2030s. The main safety challenges are related to controlled corrosion of metal container components, while the licence validity periods remain the key limitation. Information on HLW in Germany is considered complete, up to date and centralised; it is maintained in relevant state registers and periodically updated. The most recent inventory update was carried out in 2022. It is separately indicated that data on RW generated before 1970 are partially incomplete; therefore, programmes for re-characterisation and registration of historical waste are being implemented. The accounting system complies with IAEA standards and ensures transparent access to regulatory and technical information. The main challenge is the delay in implementing a final geological repository for HLW. Accordingly, there is a need to continue operation of existing facilities with licence extensions. To maintain safety, programmes are in place for regular inspection of the condition of storage facilities every 10 years, control of package tightness and repackaging procedures, including for old 200-litre drums with structural damage.

For the NPP Neckarwestheim facility, safety assessments were carried out in accordance with current legislation, including calculations of the consequences of severe accidents such as an aircraft crash. Although specific radiation impact parameters are not published, the overall safety assessment is considered high. RW retrieval from these storage facilities is not envisaged before 2046. The future HLW management strategy provides for geological disposal after the selection and construction of the relevant repository. The indicative date for a decision on final siting is 2068. All financial costs for storage and final disposal are covered by a dedicated fund established by NPP operators.

2.4.2.9 GREECE

One organisation participated in the survey: NCSRD (RE).

Greece has one RW storage facility, the NCSRD interim storage facility, which is used to store both historical and recently generated RW, including DSRS. There is no documented design operational lifetime for this facility, which creates a challenge for assessing long-term risks. The main reasons for exceeding the design operational lifetime of the storage facility are the absence of alternative storage facilities, financial constraints, and procedural and technical factors. Although NCSRD has not yet exceeded its conditional operational lifetime, ageing of RW packages and environmental impacts are already leading to deterioration of their condition. To address these problems, NCSRD is implementing monitoring and plans to upgrade the infrastructure.

Part of the historical RW was recently repackaged into 80 new drums of 280 litres each, with an estimated service life of 30 years, until 2054. Other RW remains in its primary packaging form. Storage is carried out in bulk, in containers and in primary packaging, as well as in storage facilities for DSRS. Information on RW composition remains partially incomplete due to the absence of initial data for historical RW, while initial characterisation of part of the RW has been performed and work to refine the characteristics is ongoing. The safety assessment showed minimal radiation impact even in the event of a serious external incident. However, assessments of environmental impacts in the near field have not been carried out, representing a potential gap in the safety analyses.

The main identified risk is external fire, and the main uncertainty is the absence of complete data on activity and radionuclide composition. At the same time, the overall radiological risk is assessed as low, taking into account the limited volume and low activity of the vast majority of RW.

2.4.2.10 NETHERLANDS

Two organisations participated in the survey: NRG PALLAS (TSO) and COVRA (WMO).

The national RW management system in the Netherlands is characterised by a centralised approach. The only licensed facility for long-term RW storage is COVRA (Centrale Organisatie Voor Radioactief Afval), which accepts, records, stores and provides institutional control for all waste classes: HLW, ILW, LLW and VLLW.

The strategic decision on centralisation means that all waste producers, including NRG (Nuclear Research and consultancy Group), transfer RW to COVRA. The HFR reactor and facilities at the NRG Petten site have been operating for more than 60 years.

NRG is currently temporarily storing historical RW at its site that has not yet been transferred to COVRA storage facilities due to technical limitations of the packages and the need for repackaging, in particular technical upgrading due to degradation of PVC components. However, this waste is gradually undergoing the reconditioning process.

All RW is classified and accepted in accordance with established WAC. The main storage methods include container storage, bulk storage and storage in primary packages, as well as in special tanks for liquid RW. RW data are complete, accurate and updated, although historical RW remaining at NRG facilities has limited detail and therefore requires re-verification before transport to COVRA.

According to the responses, none of the storage facilities has exceeded its design operational lifetime. The operational lifetime of COVRA is planned until 2130 and, if necessary, may be extended to 300 years, provided appropriate maintenance of the structures is carried out. If final geological disposal is not available by the end of this period, construction of new storage facilities and RW repackaging are envisaged. Since waste may lose activity during long-term storage, a reduction in the required volume for geological disposal is expected.

RW management is financed through a fund formed from contributions by waste producers. The established tariffs are controlled by COVRA, which manages the financial resources and plans the implementation of long-term disposal measures. All financing details are published in the organisation's annual reports.

Transparency is ensured through information resources, public hearings and open communication.

2.4.2.11 POLAND

One organisation participated in the survey: INCT (RE)

Poland has 3 short- and long-lived RWSF: two storage facilities No. 19 and No. 93 in Świerk, and one National Radioactive Waste Repository in Różan (NRWR).

NRWR (Różan) is the only facility with an exceeded design operational lifetime. Since alternative storage facilities are currently absent, a number of technical, procedural and financial limitations exist. This repository has been operated since 1961, and its closure was initially planned for 2020. At present, the operational lifetime has been extended to 2038–2040. Low- and intermediate-level RW is stored in different forms: in primary packages, containers, wells for DSRS sources, and as liquid waste. The condition of packages is continuously monitored through visual inspection, measurement of ionising radiation, and checking of mass and volume. RW data are generally complete: most waste is processed at the ZUOP enterprise, which prepares the relevant documentation. The main gaps relate to historical waste, for which complete records are absent or lost. To maintain the repository in proper condition, measures provided for by the Ageing Management Programme are planned, covering continuous monitoring of the condition of engineering barriers, inspection of RW packages, and repair or replacement of components when needed.

The safety assessments carried out indicate the facility's resistance to natural and man-made impacts, including radiological risks. Although specific risks were not identified in detail, the overall risk level is classified as medium.

As part of preparation for the closure of NRWR in 2034–2040, retrieval and repackaging of RW, its possible processing or transfer to a new repository or deep geological repository after 2080 are envisaged. Options for recycling and reuse are also being considered.

2.4.2.12 PORTUGAL

One organisation participated in the survey: IST-ID (RE)

Portugal has one centralised RW storage facility, the Pavilhão de Resíduos Radioactivos (PRR), run by IST and located at the CTN site. This facility has been in operation since 1961 and has undergone two expansion projects for modernization. The most recent expansion occurred in 2024, focusing on analysing historical RW for the potential clearance from regulatory control. The initial PRR license did not define a specific operational lifespan, and it has now exceeded the typical service life expected for similar facilities, leading to significant technical, regulatory, and institutional challenges that need to be addressed.

The PRR stores LLW and a limited amount of ILW, including teletherapy sources, disused sealed radioactive sources (DSRS), and liquid waste from medical and scientific institutions, as well as historical drums. Some cement and metal packages are in unsatisfactory condition, necessitating double packaging. Radioactive waste data is stored digitally in the databases of IST and at the regulatory site, but historical records are incomplete, complicating inventorying and future planning efforts.

The main challenges include the absence of a national RW management strategy that clearly outlines a disposal pathway, a national management plan that anticipates future waste generation, limited financial and human resources, technical limitations related to repackaging and transferring waste, and the lack of alternative storage options or a final disposal facility for RW.

The safety assessment of PRR analyses the impact of both natural and man-made factors. Scenarios such as earthquakes, floods, and fires have been considered, and results indicate that the radiological impact in the event of such occurrences would be limited. In 2024, a temporary area adjacent to the PRR was licensed by the regulator, APA (Environmental Protection Agency), to store historical drums, which allows for monitoring, radiological characterization, and assessment of their potential clearance from regulatory control. An annual report outlining structural changes and monitoring results is prepared.

The radiological risk associated with PRR is not clearly established or defined in the national radioactive waste management plan or in internal documents. Rehabilitation of the PRR commenced in May 2026 and will involve continuous construction efforts. The continued operation of the PRR is planned until 2040, with the possibility of using cleared areas for new waste after completing the inventory of historical drums. Public participation in this process is minimal, even though the radioactive waste national management plan was available for public discussion prior to its official release. Additionally, access to the licensing documentation for both the PRR and the adjacent facility is restricted.

2.4.2.13 SLOVENIA

One organisation participated in the survey: EIMV (TSO)

Slovenia has four main RW storage facilities: a centralised storage facility for small producers, two facilities at the Krško NPP site for HLW/ILW, and a spent nuclear fuel storage facility. Of these, two facilities have already exceeded or are approaching exceedance of their design operational lifetime:

– the central interim storage facility (CISF) for small producers at the Brinje Reactor Centre, where RW has been stored since the 1980s and the facility received its operating licence only in 2008 after reconstruction. According to the national programme, its further operation is expected approximately until 2050. RW is stored mainly as solid waste and DSRS in primary packaging, containers and wells. According to the safety assessment carried out during 1999–2004, radiological impacts are within regulatory values and the overall radiological risk is classified as low. RW retrieval is not planned within the next 15 years. The main efforts are focused on monitoring and repackaging if needed, including volume reduction through secondary use of Ra-226 applicators.

– the solid RW storage facility at Krško NPP, whose design operational lifetime was set until 2023 but was extended until 2043. HLW in this facility is encapsulated in steel or concrete containers with biological shielding and is stored according to national criteria. A repeated periodic safety assessment was carried out in 2022, and no specific remarks regarding natural or anthropogenic impacts were identified. The main problem is limited space in the storage facility, which complicates inspections and manoeuvring. Development of an ageing management programme is envisaged, as well as construction of new capacities in the absence of a final disposal decision. The radiological risk is classified as medium.

The challenges include incomplete historical records, limited access for some stakeholders, and difficulty in verification.

The main reasons for exceeding the operational lifetimes of storage facilities are identified as the absence of final disposal options, technical limitations, in particular insufficient space and limited access to RW packages, limited funding, etc.

2.4.2.14 SWITZERLAND

Two organisations participated in the survey: PSI (RE), Zwilag Zwischenlager Würenlingen AG (WMO, acting as an end-user).

Zwilag is the only licensed facility for centralised RW storage in Switzerland and accepts all radioactive waste in the country. Although there are temporary storage facilities at NPP sites, all RW is eventually transported to Zwilag.

At present, no storage facility in the country has exceeded its design operational lifetime, as the facility started operation in 2000 and will operate at least until 2074 or until the geological repository is commissioned.

Various classes of RW are received at Zwilag, including HLW, SNF, ILW and LLW, which are stored in bulk, in containers, in primary packaging, etc. The service life of packages is mostly not defined, as they undergo regular inspections and are repaired when needed. The only packages with a defined service life are containers for SNF and vitrified waste, designed for 40 years; some of them have already been in use for more than 20 years, so their service life requires extension. RW data are complete, accurate and updated, except for historical RW (before 1990), for which data may be incomplete or inaccurate.

The main reason for extending the storage facility lifetime is the absence of geological disposal. The most critical challenge is gradual package degradation, which requires regular monitoring and periodic inspections, including visual inspections of containers, measurements of neutron and gamma radiation levels, temperature control and investigation of changes in metal container seals.

According to the safety assessments carried out, the main threats were identified as an aircraft crash, floods and earthquakes. The most unfavourable scenario was identified as an aircraft crash into the RW drum storage area, which could result in a radiation impact of up to 1000 mSv per year.

The further RW management strategy provides for SNF repackaging for geological disposal in 2045–2060, implementation of final geological disposal by 2050, and closure of Zwilag in 2074. Funding for the measures is provided through the state budget and the private sector.

The responses provided by PSI state that Switzerland has two RW storage facilities, one of which has exceeded its design operational lifetime. This is the BZL facility (BZL1 and BZL2/OSPA), which was initially designed for operation until 2025, but after repeated safety assessments its operational lifetime was extended until 2065. LLW/ILW is stored at this facility in a cement matrix placed in steel drums or cubic cementitious containers. Waste that was packaged earlier must undergo re-inspection in the near future to determine the need for repackaging. The expected service life of older containers is no later than 2025, while newer containers will remain safe until 2065.

The main reason for extending the storage facility lifetime is the delay in final geological disposal, which was initially planned for 2020. The main challenge is degradation of older containers due to extended operation, which may reduce their resistance to external impacts. To manage ageing at the facility, the commissioning of an additional storage facility is planned for 2025, which will help optimise free capacity for RW storage.

In 2025, BZL submitted an application for a new licence, including expansion of the storage facility.

According to the safety assessments carried out, the main threat may be a catastrophic aircraft crash. The risk assessment confirmed that, due to the presence of cemented LLW/ILW and the proximity to the airport, the overall threat level is classified as medium. The further RW management strategy provides for extension of the storage facility lifetime until 2065, retrieval and repackaging of old containers within the next 10 years, and transfer of cubic cementitious containers to BZL2 in the following years. Final geological disposal is planned for the period 2045–2055, after which BZL and BZL2 will be closed and the site returned to its initial condition.

Continued operation of storage facilities beyond the design lifetime in Switzerland is implemented through the standard licensing procedure, which includes, in particular, public discussion (Einsprachen) at each level, access to technical reports and regulator conclusions, and public participation.

2.4.2.15 UKRAINE

Responses were provided by two organisations: SSTC NRS (TSO) and Energorisk (RE).

I. Ukraine operates more than 60 RW storage and disposal facilities, of which 28 have already exceeded their design operational lifetime or are approaching this status. Most of these facilities were created in the 1960s–1980s with the initial purpose of near-surface RW disposal. Under conditions of limited financing, lack of proper modernisation, and the presence of a significant volume of historical waste without proper documentation, the management of these facilities remains a challenge of national scale.

Ukraine applies various storage methods, including containerised storage, storage in bulk and in primary packages, as well as well-type storage facilities for DSRS. A significant part of the facilities contains both low-level and intermediate-level waste and, in some cases, high-level waste, for example RWDS Pidlisnyi and facilities in the Chornobyl Exclusion Zone. At the same time, the service life of containers is mostly undefined or unknown.

The assessment of the condition of the storage facilities revealed significant risks, such as degradation of engineering barriers, including cracks in concrete and container corrosion, possible groundwater infiltration, loss of data on RW contents and limited access to packages for inspection. Some storage facilities, in particular in Kyiv, Odesa, Dnipro, Kharkiv and Lviv, were classified as high-risk facilities requiring immediate measures for waste retrieval, reconditioning and transfer to centralised storage facilities, such as the Vector complex or RWDS Buriakivka.

The national RW management strategy provides for a gradual transition to centralised long-term storage, with a focus on facility modernisation, improvement of the monitoring system and development of a geological repository for HLW. One of the key challenges remains the completeness and reliability of the inventory: a significant part of RW packages does not have verified information on contents, activity, isotope type and physicochemical characteristics.

Ukraine is implementing measures to improve accounting: digitalisation of archival data, integration into a unified state database, repeated RW characterisation, etc.

In the long term, the main condition for safety remains the development and implementation of a strategy for retrieving RW from storage facilities that have exceeded their design lifetime, followed by reconditioning, transport and storage in accordance with modern criteria.

It is noted that public information on the number of RW storage facilities that have exceeded their design operational lifetime is not available; however, the questionnaire lists four facilities or facility groups with a potential risk of exceeding their design operational lifetime: RW storage facilities at operating NPPs, Chornobyl NPP storage facilities, facilities of the State Specialized Enterprise Central Enterprise for Radioactive Waste Management, and storage facilities of the Radon Association. For each of these facilities, RW characteristics, storage methods and general operational problems are provided.

For all the sites mentioned, data on package service life, tightness and compliance with requirements for further management are incomplete. According to the assessment provided, information on historical RW has numerous gaps: loss of archival documents, absence of unified records, difficulties with verification and limited accessibility for stakeholders. This applies especially to waste of accident origin.

The main reasons for exceeding the operational lifetimes of facilities and packages were identified as technical limitations, delays in the construction of new facilities, political and legal barriers, and insufficient funding. In the context of ageing, the most typical risks recorded are package degradation, damage to internal and external barriers, and reduced environmental resistance of facilities to external factors, including floods, seismic impacts and soil erosion. In some cases, particularly in the Exclusion Zone, these factors are supplemented by unfavourable hydrogeological conditions and limited institutional control.

Within safety assessments, risks are classified according to potential radiological consequences for the public. The overall risk level for facilities that have exceeded their service life is assessed as “high” or “medium” depending on location and waste form.

Despite an extensive storage system, Ukraine currently does not have a formalised national concept for managing storage facilities that have exceeded their design operational lifetime. This creates an urgent need for a structured inventory of such facilities; the establishment of specific approaches to assessing the condition of packages and barriers; stepwise updating of technical standards; and, critically, securing a financial mechanism for repackaging, closure or transfer of waste. Against this background, long-term preservation of institutional memory, digital data literacy and the establishment of open reassessment procedures become strategic conditions for maintaining national and radiation safety.

Planned measures include extension of storage facility lifetimes, waste retrieval and repackaging, possible recycling, transfer of RW to new storage facilities, and closure of individual facilities. Funding is provided from the state budget, the private sector and international grants. Decisions on continued operation of storage facilities are made on the basis of public consultations, risk analysis and discussions during licensing.

Ukraine expresses readiness for international cooperation within projects to expand RW conditioning capabilities in the Chornobyl Exclusion Zone, as well as in the development of common standards and technologies for RW management.

Table 1. Brief survey outcomes by countries

Country	Status of RW Storage Facilities	Waste Characteristics and Storage Methods	Safety Reassessment Findings	Identified Risks, Hazards, and Urgency	Future Strategies (Cost and Funding)
Estonia	One interim facility (Paldiski). Exceeded design lifetime (50 years); currently undergoing refurbishment.	LLW and ILW (short and long-lived) totaling \approx 1108 m^3 . Stored in concrete/metal packages and submarine reactor sarcophagi.	Radiological assessments every 5 years show impacts below thresholds. Assessments include accident scenarios like container drops or plane crashes.	Deterioration of packaging (lifting hooks corrosion) and structural cracks in walls. Retrieval urgency: > 15 years (subject to decommissioning after 2040).	RAJALA project plans construction of two final disposal facilities at Paldiski by 2040. Total activity cost evaluated at least 154 million euros. Funding: Government budget.
Poland	Three facilities. One (National Repository in Rozan) has exceeded its design lifetime (operational since 1961; closure planned for 2020).	LILW (4095 m^3), Pu-Be sources, and depleted uranium. Stored in thick-walled post-military fort buildings using bulk and containerised methods.	Assessments demonstrated resilience to natural and anthropogenic impacts. Radiological resilience is confirmed.	Hypothetical risks include human intrusion or release during repackaging. Retrieval urgency: > 15 years.	Emptying facilities and closure of Rozan repository between 2034-2040. Relocation to a new repository. Closure costs estimated. Funding: Government budget.
Portugal	One centralised storage facility (PRR). Long exceeded its design lifetime (operating since 1961); in urgent need of a new site.	LILW, spent/disused sealed sources, and liquid wastes. Stored in cement and metal drums; double drumming used for damaged packages.	Minimal requirements passed for licensing; flood/storm damage unlikely. Reference accidents considered (crushing of Ra-226 source, loss of shielding).	Risks include absence of governmental strategy, no financial/human resources, and human intrusion. Retrieval urgency: 5 to 15 years.	Temporary extension built in 2024 to clear/analyse historical waste (ongoing until 2040). Costs estimated by the PRR operator (IST). Funding: Government budget.
France	13 registered basic nuclear installations (BNIs) plus others. Some legacy facilities (e.g., Saint-Laurent silos, Saclay) face safety concerns due to age.	Vitrified waste, graphite sleeves, LLW, ILW, HLW. Methods include pools, silos, casks, and metallic drums.	Periodic safety reviews (every 10 years). For example, Saint-Laurent silos show seismic and flood concerns & Saclay waste recovery program started in 2022.	Risks include container corrosion and substantial dispersible inventory.	Prioritisation of waste retrieval and conditioning (WRC) and construction of Cigéo DGR. Funded by licensees via dedicated asset portfolios.
Slovenia	Four facilities. Two have exceeded design lifetime: CISF (refurbished 2008) and	LILW (resins, filters, evaporator bottoms) and SF. Stored in 208-L drums, stainless steel drums, and	CISF SR proved scenarios within limits. NPP periodic safety review (2022)	Risks include lack of storage capacity at NPP and insufficient knowledge exchange. Retrieval urgency: < 5	CISF extension to 2065; NPP Krško extension to 2043. New storage to be built on NPP site. Costs

	one on-site LILW storage at NPP Krško.	dry storage casks. CISF holds 89 m³.	identified aging management needs.	years (NPP); > 15 years (CISF).	allocated annually. Funding: Government and Industry.
Austria	Four interim storage halls at one site. One hall (LH12) no longer aligns with storage concept and is being cleared out. No predefined design lifetimes.	LILW-SL (1453 m³) and LILW-LL (50 m³) stored in 200-L conditioned drums (Cs-137, Sr-90, Am-241).	Safety assessments for natural/man-made impacts are done for new halls. Aircraft crash scenario identified limited release risk.	Risks include non-compliance with modern requirements and corrosion. Retrieval urgency: > 15 years (extended until 2045 due to disposal delays).	Drums being reconditioned and relocated to climate-controlled halls. LH12 dismantled by 2040. Costs covered by 2008-2020 modernisation via Government budget.
Denmark	Six facilities. One facility has an exceeded design lifetime. Data quality for historic waste is limited.	Historic and operational waste. Registered and repacked using qualified assumptions where historical data is missing.	Periodic inspections by authorities. Safety reassessments include monitoring storage environment and structural integrity.	Main challenges are drum corrosion and rising sea levels at Roskilde Fiord. New facilities will be placed on higher ground to mitigate flooding.	New storage facility expected by 2029 to serve until final disposal in 2073. Costs for DGR not yet calculated. Funding: Government budget.
Germany	57 storage facilities. Zero exceeded design life. 19 HLW facilities (e.g., Neckarwestheim) have a 40-year design life.	HLW (SNF and vitrified waste) in CASTOR casks. Legacy waste (pre-1970) is also present.	Assessments follow German Atomic Law. NPP Neckarwestheim (2006) complies with requirements for impacts like plane crashes.	License limits (40 years) for casks; first expire in late 2030s. Deterioration of older 200-L drums. Retrieval urgency: > 15 years.	License extensions for interim storage until DGR is available (site selection by 2068). Financed by a public fund from NPP operators.
Bulgaria	5 existing facilities (3 SERAW, 2 Kozloduy NPP) + 1 under construction. Design lifetime information is not publicly available.	LILW and SNF. Methods: Bulk storage, primary packages, containerised storage, and specialised underwater/dry SNF facilities.	Society lacks access to safety data. Some 'Radiana' site assessments were appealed by citisens due to IAEA inconsistencies.	Concerns include proximity to groundwater/Danube River and long-lived isotopes. Retrieval urgency: 5 to 15 years.	National Repository for LILW under construction at ‘Radiana’ site. No specific cost estimations for aging facilities. Funding: NPP RWM fund.
Ukraine	60 storage facilities. 28 with exceeded design lifetime.	VLLW, LLW, ILW, HLW, and LILW-LL (approx 800,000 m³ total). Stored in various containers and emergency pits in Chernobyl Zone.	Facilities comply with safety requirements except for Chernobyl emergency storage. Uncertainties exist regarding radionuclide transport models.	Risks include earthquakes and hurricanes. Retrieval urgency for NPP waste: > 15 years.	Lifetime extension via safety analysis and simulation. Geological disposal planned for long-lived waste. Funding: Government, Industry, and International grants.

Czech Republic	Four facilities (NPP Dukovany, NPP Temelín, UJV, SÚRAO). Zero facilities have exceeded design lifetime (projected 50-60 years).	Liquid RW (concentrates, sorbents) and Solid RW. Stored in tanks, casks, or specific premises. HAW capacity is 226.8 m^3.	Regulator controls and relicensing ensure quality. Facilities comply with Atomic Act No. 263/2016 Coll. standards.	No exceeded design life identified; environmental hazards limited by legislative optimisation levels. Retrieval planned upon DGR availability.	If DGR is not available by facility end-of-life (e.g., 2047 for UJV), new construction/reconstruction required. Strategy via decommissioning proposals.
Finland	23 storage facilities. Zero facilities have exceeded design lifetime. Licenses proactively extended with power plant lifespans.	SNF and radioactive waste (including non-nuclear sealed sources). Active record-keeping via SRIS database.	Periodic safety reviews (every 10 or 15 years) are mandatory. Re-assessment of safety needed for license extensions. Radiation releases are minor; facilities are co-located with NPPs.	No facilities currently exceed lifetime; aging management is proactive. Challenges limited to developing future waste estimates.	Disposal facility for SNF (Onkalo) is under construction. No extended interim storage periods foreseen due to available disposal routes.
Greece	One interim storage facility (NCSRD). Zero exceeded design lifetime as lifetimes have not been determined.	VLLW, LLW, ILW (approx 45 m^3) including resins, metals, and cemented sludge. Repackaged into new 280-L coated drums.	Radiation impact minimal even in fire scenarios (IAEA formulas). Near-field environmental impact not yet evaluated.	External fire is the main risk. Uncertainty exists regarding total activity of historical waste. Retrieval urgency: < 5 years.	Facility upgrade and repackaging of all historical waste. Costs partially estimated; strategies chosen based on cost. Funding: Government budget.
Netherlands	One centralised facility (COVRA) plus NRG interim storage for historic waste. Zero facilities exceeded design lifetime (COVRA to 2130).	All RW categories. Certified containers (Konrad, MOSAIK). NRG scans/re-sorts historic drums to meet COVRA criteria.	COVRA safety guaranteed by independent supervision and international standards. NRG scan systems ensure data reliability.	PVC-containing waste at NRG has degraded and requires repackaging. General radiological risk is main concern. Retrieval urgency (NRG): < 5 years.	New facilities if no repository exists by COVRA end-of-life (operational up to 300 years). Financed by waste producers via COVRA tariffs.
Switzerland	Three main facilities (BZL, ZWILAG, NPP sites). Zero strictly exceeded design life; maintained as needed until DGR ready.	HLW (vitrified), SF (4600 assemblies), ILW, LLW. Methods include cubic cement containers, drums, and CASTOR casks.	Safety assessments confirm resistance to earthquakes and flooding. Casks for high-active waste are resistant to airplane crashes.	Risks: airplane crash (near Zurich airport) and seal degradation in casks. Retrieval urgency (BZL1/2): < 5 years.	BZL extension until 2065; DGR foreseen starting 2045/55. BZL2 extension cost approx. 15.8 MCHF. Funding: Industry funds (disposal/dismantling).

2.4.3 Waste package characteristics

The survey collected data on waste classes, volumes, radiological characteristics, and physico-chemical properties per facility and per waste type. The following Table 2 summarises the main characteristics reported for the primary facilities described in the survey.

Table 2. Waste package characteristics

Country / Facility	Waste Classes	Volume	Main Radiological Characteristics	Physico-chemical Characteristics
Switzerland / BZL1 (PSI)	LLW/ILW	~1,000 m3	Alpha, beta, gamma	Drums with cementitious waste matrix
Switzerland / BZL2 (PSI)	LLW/ILW	Not specified	Alpha, beta, gamma	Cubic cement containers
Switzerland / Zwilag – HLW	High-active waste (reprocessing)	115 m3 (632 canisters)	6.2×10^{18} Bq total gamma, Sr-90, Cs-137	Vitrified in stainless steel canisters
Switzerland / Zwilag – SFA	Spent Fuel Assemblies	61 casks, 4,600 SFA	Not specified	Uranium oxide
Switzerland / Zwilag – MAW	Medium-active waste	880 m3	~99% Co-60	Solid, inert, packed for geological repository in water-resistant matrix
Switzerland / Zwilag – LAW	Low-active waste	3,200 m3	20% Co-60, 80% Cs-137	Solid, inert, packed for geological repository in water-resistant matrix
Switzerland / Zwilag – Decay	Material in decay storage	17 m3	~5× clearance level, mainly Co-60	Metal
Czech Republic / EDU	Liquid RAW concentrates, active sorbents, solid RAW	3,300 + 300 m3 liquid; 800 t solid	Not individually specified	Tanks (liquid); solid sorted
Czech Republic / ETE	Liquid RAW (concentrate, sorbents), solid RAW	520 + 200 m3 liquid;	Not individually specified	Tanks (liquid); solid sorted

Country / Facility	Waste Classes	Volume	Main Radiological Characteristics	Physico-chemical Characteristics
		500 t solid		
Czech Republic / UJV	Liquid RAW, solid RAW, HAW, Reloading	112.2 + 183 + 226.8 + 1,560 m3	Not individually specified	Various
Czech Republic / RICHARD	Disused sealed sources (non-compliant)	Up to 12,650 m3 capacity	Not individually specified	Casks; leak-tight; service life matching design life
Portugal / PRR	LILW, sealed sources, liquid wastes	Not specified	Not individually specified	Cement and metal drums; some in double drums
Slovenia / CISF	LILW (small producers)	Not specified	Not individually specified	Containers (mostly new, 2004 and later)
Slovenia / NPP Krško on-site	LILW	Not specified	Not specified	Primary packages; containerised; repacked if needed
Greece / NCSRD	LILW including sealed sources	Not specified	Not individually specified	Primary packages; 80 new drums (280L) since 2024
Estonia / Paldiski	LILW	Not specified	Not individually specified	Bulk and containerised storage
France / La Hague	HLW vitrified (CSD-V) and ILW-LL, compacted (CSD-C), bituminised waste	Not specified	Not individually specified	Stainless steel canisters (CSD-V); compacted packages in stainless steel canisters (CSD-C)
France / Saint-Laurent silos	Graphite waste (ILW-LL)	Not specified	Not individually specified	Legacy waste in silos; retrieval and reconditioning planned

Country / Facility	Waste Classes	Volume	Main Radiological Characteristics	Physico-chemical Characteristics
Ukraine / Radon sites	Mixed solid, liquid, bulk, DSRS, wells	Not specified	Exceedances identified in certain storages	Various; service life undefined or unknown

2.4.4 Applied storage methods

The following storage methods were reported across the surveyed facilities:

- Bulk Storage: reported by Portugal, Slovenia, Ukraine, Bulgaria, France, Denmark.
- Primary Packages: reported by Switzerland, Portugal, Slovenia, Ukraine, Poland, Greece, Bulgaria, France.
- Containerised Storage: reported by Switzerland, Portugal, Austria, Slovenia, Germany, Ukraine, Estonia, Poland, Bulgaria, France.
- Liquid Waste Storage: reported by Portugal, Ukraine, France.
- Wells for Spent Radioactive Sources: reported by Ukraine and Bulgaria.

Several respondents indicated that their facilities use more than one method simultaneously, particularly for heterogeneous waste inventories.

2.4.5 Service life of waste packages

Reported service life information varies significantly across respondents. Several organisations report that no formal service life is defined for packages, with inspection-based approaches instead. The information provided per respondent is as follows:

Austria

Older drums are being reconditioned and relocated to new storage halls. This reconditioning process is planned to be completed by 2040.

Bulgaria

No information on service life is publicly available for any Bulgarian facility.

Estonia

Service life of the storage facility is 100 years. Expected end of lifetime: 2097–2125.

France

Service life is reported as not applicable at the level of the overview provided.

Germany

Design life of packages is 40 years. Depending on the year of packaging, the first casks are expected to reach the end of their 40-year service life by the end of the 2030s.

Greece

Recently, a portion of waste was repackaged into 80 new drums of 280 litres. The service life of these drums is 30 years, with expected end in 2054.

Poland

Compliance of RW package condition with the information in the registration card is monitored on an ongoing basis, including visual inspection, dose rate and contamination measurements, and checks for completeness of documentation.

Portugal

Packages consist of cement and metal drums. No service life is referred to in the National Plan or in the RW operator (IST) procedures. Drums in poor condition are being placed in double drums. A 2024 extension allows for the monitoring and clearance characterisation of historical drums.

Slovenia

For the CISF, most containers are new or relatively recent, from 2004 and later. For NPP Krško on-site storage, service life is not reported, but packages are checked and repacked if needed.

Switzerland

Older packages at BZL1 have a service life at least until 2025, subject to imminent regulatory inspection, with possible repackaging if required. Newer packages at BZL2 have a service life until 2065.

Most Zwilag packages have no defined service life and are inspected regularly and repaired if needed. Transport and storage casks for SFA and vitrified waste have a design life of 40 years. Some casks have been loaded for more than 20 years; extension of their service life is under consideration.

Ukraine

The service life of RW packages is unknown or undefined for most facilities. Information on original construction is unavailable for some facilities, and physical access to assess container condition is not possible in certain cases.

2.4.6 Main results of safety reassessment

2.4.6.1 Assessment of resistance to natural and man-made impacts

The reported assessments considered different combinations of external events and hazards. These include:

- earthquakes;
- flooding;
- tsunamis;
- storms and severe weather;
- landslides;
- fires;
- aircraft crash scenarios;
- geotechnical and hydrogeological conditions;
- man-made impacts;
- site-specific external hazards.

In some cases, respondents reported that the facility had undergone safety assessment or periodic review, including assessment of natural and man-made impacts. In other cases, the response indicated that only emergency scenarios had been considered, or that no full safety reassessment had been performed for future operation.

Several responses noted that new or upgraded storage facilities had been assessed against external hazards before construction or licensing. For legacy facilities, reassessment appears more dependent on ongoing reviews, facility condition, remediation planning or future retrieval strategies.

2.4.6.2 Assessment of radiation impacts

Radiological impact assessments were reported with varying levels of detail. Some responses referred to dose calculations, accident scenarios, consequences of fire, loss of shielding, crushing of sources, gamma dose rate calculations, radionuclide migration or radiological impacts remaining within limits.

In several cases, the assessment of radiation impacts was linked to conservative or reference accident scenarios. Examples include aircraft crash and fire scenarios, release of radionuclides due to fire, loss of shielding of sealed sources, and migration of radionuclides from waste storage or disposal sites.

Some respondents reported that radiological impacts were within regulatory limits or that no significant risk to the environment or public safety was identified under the assessed scenarios. Other responses indicated that information was not published or not publicly available.

2.4.6.3 Methods and software used

The reported methods and software include both general safety assessment approaches and specific calculation tools. The responses mention:

- periodic inspections and visual checks;
- continuous tritium monitoring;
- MEVIS software;
- external expert calculations;
- IAEA-based approaches;
- SAFRAN code;
- basic radiological scenario assessment;
- RadPro Calculator;
- COSYMA software;
- Monte Carlo methods;
- MicroShield;
- RESRAD;
- HotSpot;
- ERICA;
- classical approaches used for basic nuclear installations.

Some responses also indicated that methods or software were not published or not available.

2.4.6.4 Main results of safety reassessment per country

Austria

LH12. Safety assessment was carried out by an external expert company. The main scenario assessed was an aircraft crash, deemed the only extreme scenario applicable. The hall is being cleared and drums are being reconditioned before relocation. The hall will be dismantled after clearance. Risk and hazard ranking: Low. Urgency of RW retrieval: more than 15 years.

NES Transfer Storage. Safety assessment result publicly available: worst-case scenario is a crash of a fully fuelled aircraft directly onto storage hangars with resulting kerosene fire. Worst-case dose: 20 μSv in the first year. Software and methods: unknown. No other assessments publicly available. Risk and hazard ranking: not provided.

Estonia

Paldiski Interim Storage Facility. The original military training facility was partly decommissioned and refurbished in 2008. Radiological safety assessment is conducted every five years. Software used: MicroShieldTM 6.02, RESRAD, HotSpot, ERICA. Under normal operation, radiation impacts are within limits. In case of emergency, for example a plane crash, doses to the population are approximately 2 mSv. Small cracks have been identified in the walls. Risk and hazard ranking: Low. Urgency of RW retrieval: more than 15 years.

Finland

Periodic safety reviews are done every 10 or 15 years. The storage facilities are located at NPP sites which have more notable environmental impacts. All facilities have current operating licences. Risk and hazard ranking: Low.

France

Example of Saint-Laurent-des-Eaux Silos. In the previous periodical safety review, concerns were expressed about seismic and flood resistance. No concern was identified regarding radiation impacts. Methods used: classical approach applicable to all BNIs. Main risks are linked to natural hazards. Uncertainties are linked to radiological inventories, as well as to EDF's strategy to remove sleeves from the silos and dismantle the facility. Risk and hazard ranking: Medium. Urgency of RW retrieval: 5 to 15 years. At the end of 2022, EDF submitted the dossier for dismantling the silos, including desilting operations for graphite waste recovery and reconditioning.

Germany

NPP Neckarwestheim. The safety assessment was carried out in accordance with German atomic law when the facility was commissioned in 2006. Detailed results of safety assessments and software used are not published. Risk and hazard ranking: Low. Urgency of RW retrieval: more than 15 years.

Greece

NCSRD. No assessment of storage facility resistance to natural and man-made impacts has been carried out. Software used: IAEA formulas for fire impact assessment, with reference to IAEA Generic Procedures for Assessment. Main risk: external fire. Main hazards: radiation doses to people 500 m away during fire. Main uncertainty: total activity, radionuclides present in waste, and their specific activities. Near-field environmental impact has not been evaluated. Risk and hazard ranking: Low. Urgency of RW retrieval: within 5 years.

Poland

National Repository Rozan. Assessments of resistance to natural and man-made impacts are conducted as part of safety assessments. The assessment demonstrated resilience of storage facilities to radiation impacts. Methods and software used have varied over time, including typical measurement methods and migration modelling software. Specific data on identified risks and hazards are not available. Risk and hazard ranking: Low. Urgency of RW retrieval: more than 15 years.

Portugal

PRR. No safety reassessment was carried out when the PRR started operating in 1961. Only recently have accident scenarios been included in the emergency plan of the PRR. Software used: RadPro Calculator simulator for dose rate calculations, COSYMA for radionuclide transport and radiological consequences, and Monte Carlo methods.

Natural hazards assessed include storms, local floods, landslides, earthquakes, and tsunamis. The maximum expected earthquake intensity is grade IX Modified Mercalli at the CTN site, with an estimated return period of approximately 200 years for magnitude 8. Tsunami propagation in the Tagus Estuary from a 1755-type event is considered a relevant scenario given the CTN location. The facility is located 10 metres above the Tagus River level; flooding is considered highly unlikely.

Reference accidents assessed include: crushing of a Ra-226 source during pressing, loss of shielding of a sealed Co-60 source, and a fire scenario with release of Co-60, Cs-137, and Ra-226 outside the PRR. Risk and hazard ranking: Medium, mainly due to the presence of sealed sources in the inventory. Urgency of RW retrieval: 5 to 15 years. No remediation approach has been considered.

Slovenia

CISF. A thorough characterisation of RW packages was performed between 1999 and 2004; an action plan and safety report were prepared. The IAEA approach was applied using the SAFRAN code. Radiation impact assessment showed all scenarios within limits. Recommendations for constant improvement and iterative safety assessment were made. Risk and hazard ranking: Low. Urgency of RW retrieval: more than 15 years.

Switzerland

BZL1 and BZL2. Safety assessment was carried out as part of the application for new licences for BZL1 and BZL2, including assessment of earthquake resistance, security measures such as fence and guards, and confirmation by the regulatory authority. Ongoing safety monitoring includes periodic visual inspection and continuous tritium monitoring using MEVIS software. No significant risks were identified beyond the airplane crash scenario, linked to proximity to Zurich Airport, approximately 30 km.

Resistance to natural and man-made impacts: resistance to airplane crash assessed as the primary scenario. Risk and hazard ranking: Low. Urgency of RW retrieval: within 5 years for BZL1, subject to regulatory inspection of old packages.

Zwilag. Safety assessment was performed by an external company. Main scenarios assessed include airplane crash, flooding, and earthquake. The probability of an airplane crash is below 10^{-6} per year for medium-active storage; high-active storage casks are designed for airplane crash. Flooding was assessed for a 1/10,000-year event, and earthquake for 10^{-4} per year. Radiation impact assessment: worst-case scenario in case of airplane crash on the storage of RW drums with raw combustible waste gives doses below 1,000 mSv/a. Risk and hazard ranking: Low, as high risks must be mitigated to obtain an operating licence. Urgency of RW retrieval: more than 15 years. Complete remediation is planned and financed through a dedicated waste disposal and dismantling fund.

Ukraine

Radon Sites. Safety reassessment was conducted using SAFRAN, based on the IAEA Safety Assessment Methodology. At the Kyiv Radon Central Industrial Site, the facility shows strong resistance to natural and man-made hazards, with no identified risks from flooding, seismic activity, or other external events at significant levels.

For solid waste storages nos. 5–10, calculated exposure levels exceed permissible limits, requiring remediation. The main risks identified are structural degradation of engineered barriers, including corrosion of containers and cracking of concrete; groundwater contamination risks, particularly due to seasonal flooding and hydrogeological changes; and long-term structural integrity concerns. Risk and hazard ranking: High, Medium, and Low depending on the specific facility. Urgency of RW retrieval: 5 to 15 years.

2.4.7 Main identified risks and urgency of retrieval

The urgency of retrieval was reported differently across facilities. Among the facility-specific responses where urgency was provided:

- several facilities indicated retrieval or action within 5 years;
- several indicated a timeframe of 5 to 15 years;
- the most frequent category was more than 15 years.

The shorter timeframes were generally associated with facilities where repackaging, upgrading, lack of storage capacity, remediation or safety-related actions are already relevant. Longer timeframes were reported where facilities are still considered suitable for continued storage, where final disposal or future facility development is planned further in the future, or where the current lifetime has not yet been reached.

Identified risks and urgency of retrieval based on these reassessments and identified hazards, the urgency of radioactive waste retrieval varies significantly across the surveyed countries:

– High urgency (< 5 years): Several countries classify their retrieval and remediation operations as urgent. Greece, the Netherlands (for historical waste at NRG PALLAS), Switzerland (BZL facilities), and Slovenia (due to capacity limits at NPP Krško) report an urgent need for retrieval or action. Ukraine classifies several of its facilities as high-risk objects requiring the immediate retrieval, reconditioning, and relocation of waste. Portugal's centralised facility (PRR) is also considered a high radiological risk due to the presence of high-activity disused sealed radioactive sources, limited institutional resources, and the lack of a decommissioning strategy, despite having passed minimal licensing requirements.

– Medium urgency (5 to 15 years): Switzerland's ZWILAG facility and Ukraine's Radon facilities view retrieval on a 5 to 15-year horizon. In France, the regulatory code requires owners of intermediate-level, long-lived waste (ILW-LL) produced before 2015 to package it no later than 2030. Furthermore, EDF plans to begin the urgent desilting and retrieval of graphite waste from the Saint-Laurent silos in the early 2030s to reduce the dispersible inventory. Bulgaria and Portugal also fall into this medium-term timeframe for necessary retrieval actions.

– Lower urgency (> 15 years): Countries whose interim storage extensions are closely tied to the future completion of DGRs generally view complete retrieval as a long-term goal. This includes Austria (aiming for final clearance by 2040-2045), Estonia (post-2040), Germany (current lifetime ends in 2046), Poland (planned for 2034-2040). Ukraine also lists a >15 year retrieval urgency specifically for its NPP waste. While these countries recognise the need for eventual retrieval, their current storage conditions, ongoing modernisation efforts, and proactive aging management programs are deemed stable enough to safely defer retrieval until deep geological repositories or new centralised facilities become available.

Table 3. Main identified risks and urgency of retrieval

Country	Facility Name	Retrieval Urgency Category	Estimated Retrieval Timeframe	Safety Findings and Vulnerabilities
Ukraine	Emergency RW storage facilities (Chornobyl exclusion zone)	High	Immediate	Non-compliance with current safety standards; uncertainties regarding unverified contents and radionuclide transport models
Switzerland	BZL facility	High	< 5 years	Located 30 km from Zurich airport; worst-case impact remains within regulatory limits
Slovenia	NPP Krško (CISF / Solid waste storage)	High	< 5 years	Severe lack of storage capacity; facility almost full, making visual inspections and aging management difficult
Greece	NCSRD interim storage facility	High	< 5 years	Uncertainties regarding exact radiological inventory and total activity in legacy waste; near-field environmental impacts to be evaluated
Netherlands	NRG (Historical waste)	High	< 5 years	Requires immediate repackaging
Portugal	Radioactive Waste Pavilion (PRR)	High / Medium	5 to 15 years	; Absence of a national strategy considering disposal, limited institutional resources; lack of a decommissioning strategy and uncertainties about historical inventory
France	Saint-Laurent-des-Eaux silos	Medium	By 2030	Requires geotechnical reinforcements; uncertainties regarding exact radiological inventory
Estonia	Paldiski interim storage	Lower	> 15 years	Rising groundwater poses stability risk; cracks require remediation
Austria		Lower	> 15 years	Very limited release risk; current storage deemed stable enough for future deep geological repository
Germany	NPP Neckarwestheim	Lower	> 15 years	Compliance with high safety standards for extreme impacts
Ukraine	NPP's interim storages	Lower	> 15 years	Compliance with high safety standards

2.4.8 Future strategies and planned or implemented approaches for lifetime management

Austria

Lifetime extension of LH12 storage hall: extension needed due to unavailability of a disposal facility; extended until 2040. Reconditioning of historic waste packages: ongoing. Recycling/reprocessing: metal melting, possible reuse of sources, release of decayed waste, applied whenever applicable. Relocation to new storage halls at NES: retrieval, reconditioning, and relocation are ongoing. Deep geological disposal: not foreseen in Austria. Storage closure: only when final disposal is operable and all RW has been transferred; no clear timeline available.

Bulgaria

No information is publicly available on approaches, timescales, or plans for any Bulgarian RW storage facility.

Estonia

Current lifetime of the Paldiski facility: until 2039. After 2040, lifetime extension with accompanying safety analysis and procedures would be required if no final repository is available. RW retrieval and repackaging, recycling, and relocation: not applicable at present. The facility is subject to decommissioning after 2040 as part of the broader Paldiski site decommissioning project. The total cost of the RAJALA project, construction of a final repository, has been estimated; cost of lifetime extension has not been assessed.

Finland

Extension of nuclear facility lifetimes requires a licence for a fixed term; periodic safety reviews are required for licences exceeding 10 years, or 15 years for nuclear waste. All facilities currently operate within their licences. Operating licence for disposal facility for spent nuclear fuel is under evaluation by the authorities.

France

The general strategy in France is to prioritise WRC, Waste Retrieval and Conditioning, projects with respect to: (i) safety, including reduction of the dispersible inventory of storage facilities not meeting current safety requirements; and (ii) optimisation of decommissioning schedules. The Environment Code requires owners of ILW-LL produced before 2015 to package it no later than 2030. Due to technical complexity, delays and cost overruns have occurred. The regulator has adopted an approach of monitoring WRC progress in the short term, with 5-year milestones, while maintaining the long-term 2030 objective.

Germany

For NPP facilities, example: Neckarwestheim, licence extension is foreseen due to lack of a final disposal site for HLW, with current lifetime ending in 2046. No repackaging, recycling, or relocation measures are currently planned. No remediation measures are considered as the facility's 40-year lifetime ends in 2046.

Greece

Lifetime extension: new containers with anticorrosion coating and facility upgrade; planned service life 50 years. RW retrieval and repackaging: segregation, characterisation, and repackaging in new drums; timeframe 5 years. Recycling/reprocessing: not planned. Relocation: not planned.

Poland

Closure of the Rozan repository: planned for 2034–2040; preparation of Repository Closure Programme and closure permit are required. RW retrieval and repackaging: long-lived waste to be retrieved and repackaged before closure; timeframe 2034–2040. Recycling/reprocessing: to be considered in parallel; timeframe 2034–2040. Relocation to new storage: all waste to be relocated to a new repository; timeframe 2034–2040.

Portugal

PRR. A physical extension was built in 2024 to allow for the clearance of historical drums and to update the waste inventory. This is not aligned with an overall facility remediation strategy. The timeframe for this clearance process is 2024–2040. Recycling/reprocessing: not available. Relocation: free area may be used for new waste storage once historical waste is cleared, 2024–2040. Deep geological disposal and formal storage closure: not considered in the national waste management strategy.

Slovenia

Lifetime extension via relicensing every 10 years with a safety report and assessment. RW retrieval and repackaging: performed when needed. Recycling/reprocessing: applicable for some isotopes requiring global management. No relocation to new storage is planned at present. An aging management plan is to be developed; new storage options are to be constructed on site; transfer to disposal is envisaged as soon as possible.

Switzerland

BZL1. Application for extension of operation until 2065 submitted. RW retrieval and repackaging: subject to inspection results in the next 10 years; outcome not determined yet. Extended interim storage may result in clearance options for old packages, but no regulations yet exist. Partial transfer of cubic cementitious containers to BZL2 is planned. Deep geological disposal is foreseen starting around 2045–2055. Storage closure: planned for 2065.

BZL2. Application for operation until 2065, licence pending. Retrieval and repackaging: initial inspection of BZL1 waste packages to be performed from 2025; later for cubic cementitious packages. Deep geological disposal: starting approximately 2045–2055. Storage closure: 2065.

Zwilag. Lifetime extension is not planned for the time being, with no formal design lifetime. SFA repackaging for geological repository: planned for 2045–2060. Recycling/reprocessing: not planned, not authorised in Switzerland at present. Relocation to new storage: not considered. Deep geological disposal: in development; estimated start around 2050. Storage closure: planned for 2074.

Ukraine

The approach is based on periodic safety reassessments. For Radon facilities: lifetime extension via periodical renewal based on safety reassessment results. RW retrieval and repackaging: planning and design for solid and liquid RW; ongoing for disused sealed radioactive sources, DSRS; timeframe 5–10 years. Recycling/reprocessing: planning and design for solid and liquid RW; ongoing for DSRS; timeframe 5–10 years. Two remediation scenarios have been assessed under INSC project 04/01/14C: Scenario 1 — Accelerated Retrieval and Scenario 2 — Sequential Retrieval. Cost estimates for both scenarios have been produced.

2.4.9 Cost estimation and funding sources

Financial constraints remain one of the most significant hurdles to implementing waste retrieval and conditioning programs, particularly for SIMS, which sometimes lack well-defined post-operational control strategies or institutional responsibilities for aging facilities. To address facilities operating up to or beyond their design lifetimes, Member States have adopted diverse forward-looking approaches based on their specific hazard levels, waste volumes, and economic capabilities.

The future strategies planned or implemented by the surveyed countries generally fall into four main categories:

- Modernisation and lifetime extensions: several countries are upgrading existing infrastructure to safely extend storage durations until final disposal becomes available. Germany plans to extend licenses for its interim storage facilities until a DGR is established, with site selection anticipated by 2068. Slovenia plans to extend the lifespan of its Central Interim Storage Facility (CISF) to 2065 and its Krško NPP storage to 2043, while also preparing to build new storage on the NPP site. Switzerland has successfully extended the license for its BZL facility to 2065 following safety reassessments.

- Repackaging and reconditioning: for facilities where waste packages are degrading, aggressive repackaging campaigns are underway. France has mandated a Waste Retrieval and Conditioning (WRC) program, setting a strict regulatory deadline to repackage all ILW-LL produced before 2015 by the year 2030. Austria is actively super-compacting historical waste, transferring it to new climate-controlled halls, and plans to fully dismantle its outdated LH12 hall by 2040. Portugal constructed a temporary extension in 2024 to clear and analyse historical waste using "double drumming" methods; this effort is expected to run until 2040. Greece is currently upgrading its facility and repackaging historical waste into new 280-liter coated drums with an estimated 30-year lifespan extending to 2054.
- Relocation to new interim or final repositories: Finland is proactively avoiding exceeded interim lifetimes altogether by constructing the ONKALO deep geological repository for spent nuclear fuel. Poland plans to completely empty and close its aging Rozan repository between 2034 and 2040, eventually relocating long-lived waste to a new repository after 2080. Estonia's RAJALA project aims to construct two final disposal facilities at the Paldiski site by 2040. Denmark expects to open a new storage facility placed on higher ground by 2029 to serve until a final DGR is ready in 2073.
- Lack of strategic decisions: conversely, some countries currently lack structured long-term plans. Bulgaria does not have specific, publicly available strategies or cost estimations for its aging facilities. In Portugal, although temporary repackaging is ongoing, there is no official final decision regarding the ultimate modernisation or closure of the centralised PRR facility.

Information on cost estimations for lifetime extension and related approaches is limited across respondents. The available data is provided in Table 4.

Table 4. Information on cost estimations for lifetime extension and related approaches

Country / Organisation	Cost Information Provided
Switzerland / PSI	Extension (BZL2): approximately 15.8 million CHF. Annual operational costs for BZL1 and BZL2 combined: approximately 1.2 million CHF. Zwilag. Costs for final repository of RW and dismantling of installations are estimated and updated by an independent organisation every 5 years (no specific figure provided in the survey).
Portugal	Costs estimated by the operator IST. Specific approaches were chosen based on those costs (no specific figures provided).
Austria	New storage facilities constructed and in use; costs included in the 2008–2020 modernisation project. Main driver was technical and safety requirements, not cost minimisation. Reduction of future disposal costs is a secondary consideration. No cost information is publicly available.
Netherlands	No direct cost information provided; notes that if COVRA's facilities reach end of lifetime without available disposal facility, new facilities will be built and waste repackaged and transferred.
Bulgaria	Future cost estimation is recommended when specific strategies are developed. Rational decisions and minimisation of costs should guide the choice of approach. No cost information is publicly available.

Country / Organisation	Cost Information Provided
Slovenia	Costs assessed and allocated in the annual work plan.
Germany	No cost information provided.
Estonia	Cost of lifetime extension not assessed; cost of the RAJALA project (final repository construction) has been estimated. No specific figures provided.
Finland	Licensees have full financial liability.
Poland	Only closure costs for the Rozan repository have been estimated; costs for waste relocation steps have not been estimated.
Greece	Costs of planned approaches partially estimated; preferences partially determined based on cost levels. No specific figures provided.
Denmark	Costs for deep geological disposal not calculated; timeframe too distant.
France	Under the polluter-pays principle, radioactive materials and waste management is financed by nuclear licensees. Provisions are made by the three main licensees (Orano, CEA, EDF) under the 2006 Act on Management of Radioactive Materials and Waste. Cost estimations are reviewed and controlled by the State.
Ukraine	Preliminary cost estimates for Scenario 1 (Accelerated Retrieval) and Scenario 2 (Sequential Retrieval) have been assessed under INSC project 04/01/14C. No specific figures provided in the survey.

To secure the economic viability of these long-term strategies, countries rely on distinct funding models, largely divided along the lines of SIMS and LIMS:

- Government budgets: SIMS, which typically handle smaller volumes of waste from medical or research applications, rely predominantly on national government budgets. This is the primary funding source for Austria, Denmark, Estonia, Greece, Poland, and Portugal.
- Industry funds (polluter-pays principle): countries with large nuclear power programmes finance their extended storage and final disposal through dedicated funds collected from waste producers. In France, nuclear licensees (like EDF, Orano, and CEA) are required by law to assess long-term nuclear costs and create a portfolio of dedicated assets to cover these provisions, a process continuously monitored by the State. In Germany, a dedicated fund was set up by all NPP operators and is now managed by a public organisation to finance all activities concerning final disposal. In the Netherlands, waste producers pay tariffs to COVRA upon waste transfer, and COVRA manages this fund to realise final disposal. Switzerland utilises a dedicated, independently updated waste disposal and dismantling fund.
- Mixed funding: a few countries use a hybrid approach. Ukraine relies on a combination of government budgets, industry contributions, and international grants to manage its complex, legacy-heavy inventory. Slovenia also allocates costs annually through a mix of government and industry funding.

Because final geological disposal sites are either still in development or facing severe delays across Europe, the extended interim storage of RW has become a standard necessity rather than an exception. The surveyed countries have adopted a range of strategies to manage this reality, with varying degrees of financial planning and structured funding.

The primary strategies for managing aging facilities revolve around lifetime extensions, continuous relicensing, proactive repackaging, and eventual transition to long-term geological disposal:

- Lifetime extensions and relicensing: many countries plan to extend the operation of current facilities for several more decades. In Austria, due to the unavailability of a disposal facility, the interim storage period has been extended to 2040–2045. Germany expects to extend licenses because a final disposal site for High-Level Waste (HLW) will not be available when current licenses expire in 2046, with site selection not expected until 2068. In Switzerland, applications are being made to extend the operation of the BZL facilities until 2065, with final geological disposal foreseen to start around 2045 to 2055. In the Netherlands, the centralised COVRA facility is intended to operate until 2130, though studies suggest present facilities could operate for up to 300 years given proper maintenance. Slovenia plans to renew licenses every 10 years, with the closure of its Central Interim Storage Facility (CISF) and NPP Krško storage projected for 2050 and 2043, respectively.
- Active remediation, repackaging, and facility upgrades: to ensure safety during these extended periods, active remediation is heavily prioritised. France’s strategy prioritises waste retrieval and conditioning projects based on safety, specifically aiming to reduce the dispersible inventory of older storage facilities that no longer meet current safety requirements. Greece plans to segregate, characterise, and repackage historical waste into new drums with anticorrosion coatings within 5 years, extending the facility's life by 50 years. Portugal recently built a new extension (2024–2040) to process and clear historical waste, freeing up space for new storage.
- Transition to final repositories: for many nations, interim storage closure is entirely dependent on the future availability of DGRs or near-surface disposal sites. Poland plans to close its Rozan repository between 2034 and 2040, requiring waste to be retrieved, repacked, and relocated to a new repository, with deep geological disposal targeted for after 2080. Estonia plans to safely decommission its Paldiski interim storage by 2060, following the construction of a new final disposal facility expected to be operational by 2040. Denmark foresees completing a new storage facility by 2029, which will precede final disposal planned for 2073.
- Deep borehole as an alternative strategy is being actively explored by SIMS like Denmark, Slovenia, and The Netherlands (research phase). It may help to avoid the construction of massive surface storage life-extensions or mined repositories by using deep boreholes for HLW/SNF. DBD viewed as a potential game-changer to reduce the duration of interim storage required.

Table 5. Synthesis information on cost estimation and funding sources

Country	Operational Timeframe	Cost Estimation	Funding Source	Strategic Status (Inferred)
France	Repackaging by 2030	No public data available	Dedicated asset portfolios funded by licensees (EDF, Orano, CEA)	Active Remediation
Austria	Dismantle LH12 by 2040; interim storage to 2040-2045	Integrated into 2008-2020 modernisation project	National Government Budget	Active Remediation
Slovenia	CISF closure by 2050; NPP storage to 2043	Assessed and allocated in yearly work plans	Mix of government and industry funding	Active Remediation

Country	Operational Timeframe	Cost Estimation	Funding Source	Strategic Status (Inferred)
Estonia	Operational by 2040; decommission interim storage by 2060	Approximately €154 million	National Government Budget	Structured Plan
Switzerland	To 2065; final disposal starting 2045-2055	For PSI facilities: 15.8 million CHF (BZL2 construction); 1.2 million CHF (annual operation for BZL1 and BZL2). For ZWILAG - data is not available	Industry funds (Disposal and dismantling fund)	Structured Plan
Poland	Close Rozan 2034-2040; new repository after 2080	Estimated for closure only; relocation costs not calculated	National Government Budget	Structured Plan
Netherlands	Intended to 2130; potentially up to 300 years	Theoretically self-compensating via decay-related savings	Waste producers via COVRA tariffs	Structured Plan
Denmark	Open 2029; final DGR in 2073	-	National Government Budget	Structured Plan
Germany	Site selection by 2068; current licenses expire 2046	-	Public fund provided by NPP operators	Structured Plan
Greece	To 2054 (30-year drum lifespan)	-	National Government Budget	Active Remediation
Ukraine	-	No public data available	Government budget, industry, and international grants	Active Remediation
Portugal	2024-2040	-	National Government Budget	Lacking Formal Strategy
Finland	Not in source	-	State Nuclear waste Management Fund (annual payments by licencess)	Structured Plan
Bulgaria	-	No public data available	Not in source	Lacking Formal Strategy

3. Workshop

As an integral part of Subtask 3.2, a dedicated workshop was organised to support the exchange and discussion of radioactive waste management strategies for situations where storage extends beyond, or has already exceeded, the original design lifetime of facilities and/or waste packages. The workshop was intended to build on the findings of the survey analysis and to move the discussion towards the identification of specific and prioritised R&D recommendations. In particular, the workshop aimed to clarify what further work is needed, which actors could contribute to it, and what practical impact such work could have on the safe long-term management of radioactive waste.

The main objectives of the workshop were to:

- define priority gaps and needs where further research, methodological development, practical tools, or international cooperation could provide added value;
- formulate specific R&D recommendations, including possible next steps, responsible or best-placed actors, and the expected benefits for WMOs, REs, TSOs, CSOs and other stakeholders.

In this way, the workshop served as an expert discussion platform for translating the collected evidence into a more structured set of future-oriented priorities. Its outcomes form an important input to the present report and support the development of practical recommendations for further work in [9].

3.1 Participants

The workshop brought together Task 3 partners and end-users online. A total of 20 participants from 12 countries, representing 13 organisations, took part in the workshop.

Table 6. Distribution of the workshop participants by countries and types or organisations

Country	SIMS/ LIMS	Organisation	Type of organisation	Role in Task 3	Number of participants
Austria	SIMS	Nuclear Engineering Seibersdorf (NES)	WMO	Partner	1
Bulgaria	LIMS	Nuclear Transparency Watch (NTW)	CSO	Partner	1
Denmark	SIMS	Nuclear Transparency Watch (NTW)	CSO	Partner	1
Finland	LIMS	Technical Research Centre of Finland (VTT)	TSO	Partner	1
France	LIMS	French Authority for Nuclear Safety and Radiation Protection (ASNR)	TSO	Partner	2
Germany	LIMS	DMT GROUP	Industry	Partner	1
Greece	SIMS	National Centre For Scientific Research Demokritos (NCSRD)	TSO	Partner	1
Netherlands	SIMS	NRG PALLAS	TSO	Partner	1
		Central Organisation For Radioactive Waste (COVRA)	WMO	Partner	1
Portugal	SIMS	Associação do Instituto Superior Técnico para a Investigação e Desenvolvimento (IST-ID)	RE	Partner	2

Country	SIMS/ LIMS	Organisation	Type of organisation	Role in Task 3	Number of participants
Slovenia	SIMS	Milan Vidmar Electric Power Research Institute (EIMV)	TSO	Partner	1
Switzerland	LIMS	Paul Scherrer Institute (PSI)	RE	Partner	2
		Zwischenlager Würenlingen AG (ZWILAG)	WMO	End-user	1
Ukraine	LIMS	State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS)	TSO	Partner	4

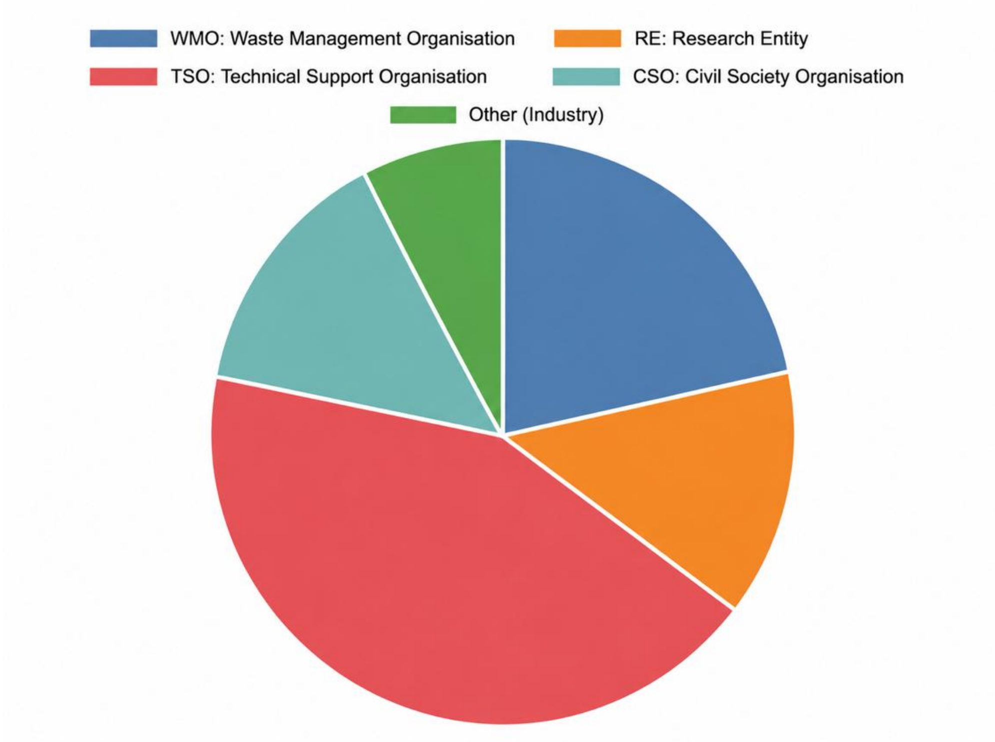

Figure 4 Distribution of organisations that took part in the wokshop by type

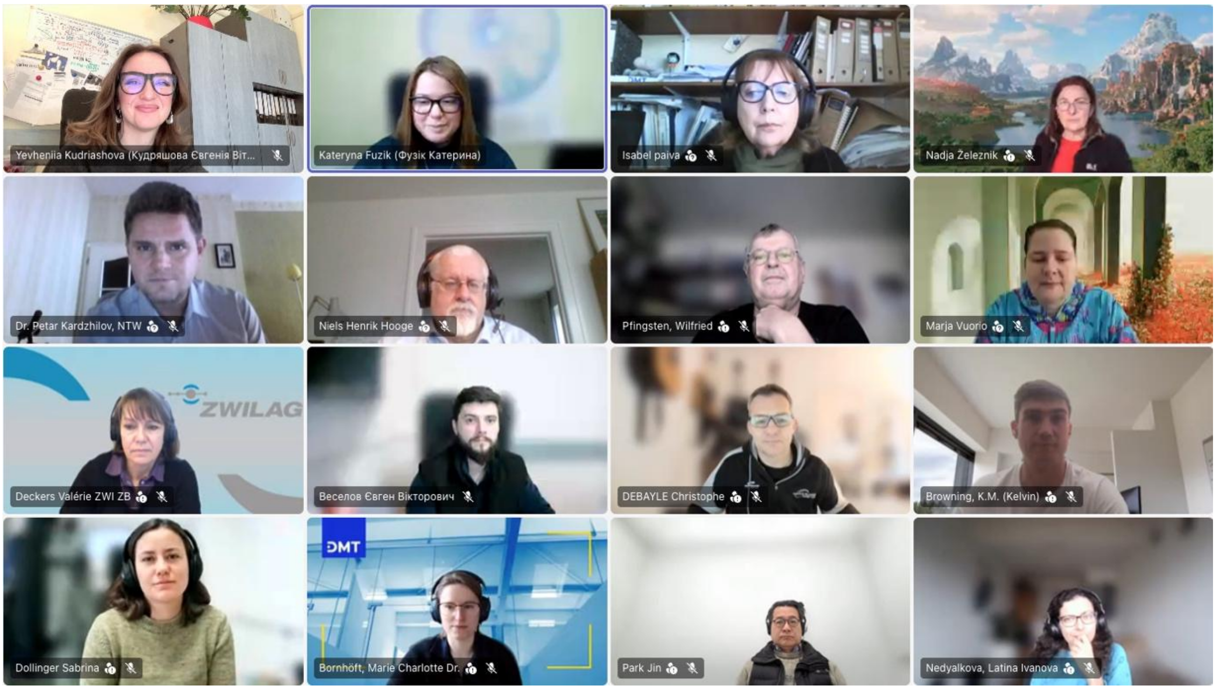

Figure 5 Photo of the Task 3 Workshop 2 participants

3.2 Agenda

The agenda of the event was structured to encourage both structured information-sharing and interactive dialogue. Following a welcome session and the presentation of objectives, the workshop featured presentations on the follow-up from the first Task 3 Workshop [4], the input to the ASTRA WP Position paper on mutual understanding on alternative RWM strategies for tasks [10], and civil society perspectives. The core of the workshop was a 55-minute interactive breakout session, where groups were given 5 minutes to select 3 topics from a menu of 9 pre-identified challenges, 40 minutes to discuss and answer 5 key questions for each topic, and 5 minutes to wrap up their findings. Following the breakout sessions, groups provided short wrap-ups, and concluded with a discussion on the next steps. The full agenda of the workshop is included in Appendix 1.

3.3 Interactive breakout session discussions

During the workshop, participants worked with a menu of nine pre-identified challenge topics related to radioactive waste long-term storage:

1. Lifetime definition and decision points for extended storage - the need to define clear criteria for when storage can continue, and when upgrading, retrieval, repackaging or closure should be considered.
2. Practical ageing management tools for packages, structures and systems - the need for practical methods to monitor degradation and support timely actions before ageing leads to safety or operational problems.
3. Predictive and probabilistic tools for ageing and risk-informed decisions - the need for validated models and simple decision-support tools to prioritise actions across multiple packages and facilities.
4. Technical solutions for ageing management and barrier strengthening - the need for proven and implementable measures for maintenance, repair, upgrading and strengthening of safety barriers.
5. Retrievability and repacking under degraded conditions - the need to develop safe and workable methods for retrieving and repackaging waste, especially where packages may be degraded or difficult to handle.

6. Waste Acceptance Criteria evolution and bridging methods - the need to address the risk that stored waste packages may no longer meet future disposal acceptance criteria without additional conditioning or repackaging.
7. External impacts and climate resilience for extended storage - the need to reassess and improve the resilience of older storage facilities against current and future external hazards.
8. Emerging waste streams - the need for early assessment of future waste characteristics, volumes and suitable storage or conditioning routes for new reactor and fuel technologies.
9. Social science and humanities aspects - the need to address transparency, trust, stakeholder involvement, safety concerns and intergenerational responsibility in long-term storage decisions.

These topics were prepared to support a structured discussion and to help participants move from the general identification of problems towards more concrete R&D needs. To facilitate in-depth and interactive discussions, participants were divided into four designated breakout groups. Each group was asked to collectively select three topics for further discussion. For each selected topic, participants were invited to consider the core problem to be addressed, possible R&D steps, the actors best placed to contribute, and the indicative timeframe for implementation.

All proposed topics, except Topics 5 and 7, were selected by at least one group and discussed during the breakout sessions. The outcomes of the discussions for each selected topic are summarised below.

3.3.1 Topic 1: Lifetime definition and decision points for extended storage

3.3.1.1 Context and technical challenge

Participants highlighted that extended storage is not always supported by clear and harmonised decision-making criteria. Facilities originally established as temporary storage solutions sometimes do not have a clearly defined end-of-life date. As disposal routes could be delayed, storage is often extended step by step, but the conditions for continued operation, upgrading, retrieval, repackaging or closure are not always clearly defined. A further issue is the lack of common understanding across countries regarding the definition of lifetime extension and the regulatory expectations linked to it.

3.3.1.2 Key identified gaps:

– absence of precise safety-related criteria for lifetime extension;
– unclear decision points for choosing between continued storage and alternative actions;
– differences between national regulatory frameworks;
– need to account for changing external conditions, including climate change and geopolitical factors;
– data gaps related to facility history, ageing state and legacy waste packages.

3.3.1.3 Proposed next research steps:

– digitalisation and recovery of historical information;
– detailed investigation and characterisation of facility condition;
– assessment of the current ageing state of facilities, structures and packages;
– improved understanding of radionuclide transport in ageing materials, including legacy waste packages;
– development of practical tools for defining or estimating remaining lifetime;
– modelling of external events and impacts, such as earthquakes and other relevant hazards.

3.3.1.4 Stakeholders

This requires a multi-actor approach involving WMOs/operators (practical implementation, facility knowledge, cost-benefit considerations), regulators and TSOs (development of criteria, methods and safety expectations), REs (testing, modelling and methodological support), CSOs and other stakeholders (input on reasonableness, transparency and public confidence).

3.3.1.5 Expected benefits and impact:

- clearer basis for decisions on continued storage, upgrading, retrieval, repackaging or closure;
- more timely actions before safety or operational problems emerge;
- improved consistency and common understanding between countries;
- better coverage of data gaps;
- stronger support for risk-informed and transparent decision-making;
- improved basis for assessing the cost-benefit of different management strategies.

3.3.1.6 Indicative timeframe

Participants suggested that practical criteria, tools and facility assessments could be developed in the short term, within 1-3 years. Broader harmonisation work, modelling activities and consideration of changing external conditions may require a 3-5 year timeframe.

3.3.2 Topic 2: Practical ageing management tools for packages, structures, and systems

3.3.2.1 Context and technical challenge

Participants noted that containers, structures and safety important systems may gradually degrade during extended storage due to corrosion, seal degradation, concrete ageing or loss of performance. The key challenge is to monitor and assess this ageing in a practical way and to take timely actions before minor degradation develops into safety or operational problems. Particular attention was given to the need for reliable information, practical inspection tools and simple assessment methods that can support decisions on continued storage or lifetime extension.

3.3.2.2 Key identified gaps:

- incomplete or insufficiently digitalised historical information;
- uncertainties in the accuracy and accessibility of data;
- lack of simple tools for ageing assessment and modelling;
- limited ability to identify waste package contents without opening drums;
- need for practical on-site inspection methods to detect corrosion, degradation and loss of performance;
- uncertainty regarding the continued functionality of safety important systems during long-duration storage.

3.3.2.3 Proposed next research steps

- digitalisation and recovery of past information;
- development of simple operational modelling tools;
- benchmarking of available ageing evaluation tools;
- long-term experimental studies on drum ageing;

- development of practical inspection and monitoring protocols;
- development of tools and checklists to assess the possibility of safe lifetime extension.

3.3.2.4 Stakeholders

The work should involve WMOs/operators (access to facilities, packages and operational data), regulators and TSOs (assessment criteria and safety expectations), REs (develop and test tools and methods) and, where relevant, CSOs (contribute to transparency and trust in long-term safety decisions).

3.3.2.5 Expected benefits and impact:

- earlier detection of ageing and degradation;
- more consistent and practical evaluation tools;
- better support for decisions on lifetime extension;
- reduced uncertainty regarding package condition and contents;
- improved safety during continued storage, retrieval and disposal preparation;
- improved knowledge sharing and avoidance of duplicated efforts.

3.3.2.6 Indicative timeframe

Initial work on digitalisation, practical tools, benchmarking and inspection protocols could start within 1-3 years. Longer-term activities, such as ageing experiments and validation of tools for different package types, may require a period extending beyond 3 years.

3.3.3 Topic 3: Predictive and probabilistic tools for ageing and risk-informed decisions

3.3.3.1 Context and technical challenge

Participants noted that when many waste packages and several storage facilities are involved, it may become difficult to identify which packages, facilities or degradation processes require priority attention. In the absence of simple predictive tools, databases or practical “look-up” approaches, decisions may rely too heavily on expert judgement and may vary between organisations or countries. The main challenge is therefore to develop reliable, easy-to-use tools that can support risk-informed and consistent decisions on monitoring, inspection and further management actions.

3.3.3.2 Key identified gaps:

- need for simple, operational tools to support decision-making;
- limited availability of reliable data for predicting package evolution;
- need for access to databases, while considering confidentiality constraints;
- uncertainties regarding degradation processes inside waste packages and matrices;
- need to consider combined chemical and radiological risks;
- limited ability to forecast how package degradation may affect safety barriers during longer-term storage.

3.3.3.3 Proposed next research steps

- development of predictive tools and software codes to forecast package behaviour during extended storage;

- establishment of databases containing key information on waste packages, degradation mechanisms and possible future processes;
- improvement of package monitoring to provide data on degradation of waste matrices and barriers;
- development of approaches to address combined chemical and radiological risks, including specific material interactions such as aluminium/concrete systems or liquid waste forms;
- development of uniform monitoring rules and practical tools for quick assessment of storage situations.

3.3.3.4 Stakeholders

The main actors for this topic should be WMOs/operators (hold the operational data and are responsible for package monitoring and decision-making), REs (contribution to additional R&D, including model development, testing and validation), regulators and TSOs (support the definition of data needs, safety expectations and criteria for using predictive tools in regulatory or safety assessment contexts).

3.3.3.5 Expected benefits and impact:

- improved ability to foresee package degradation and related safety implications;
- more reliable and consistent decision support for monitoring and management actions;
- faster assessment of storage situations;
- improved prioritisation of packages or facilities requiring attention;
- better understanding of chemical, radiological and material interactions during extended storage;
- reduced dependence on case-by-case expert judgement.

3.3.3.6 Indicative timeframe

Participants considered this topic as a near-term priority. Initial development of practical tools, databases and monitoring approaches could begin as soon as possible and be implemented within 1-3 years, with further validation and refinement continuing as more operational data become available.

3.3.4 Topic 4: Technical solutions for ageing management and barrier strengthening

3.3.4.1 Context and technical challenge

Participants noted that detecting ageing is only the first step. Facilities also need proven and deployable technical measures to maintain or strengthen safety barriers over extended storage periods. In some cases, degradation processes in waste matrices or structural materials are not fully understood, making it difficult to select the most appropriate maintenance, repair or barrier-strengthening option. The main challenge is therefore to identify technical solutions that are not only scientifically sound, but also realistic and applicable in existing storage facilities.

3.3.4.2 Key identified gaps:

- limited understanding of some reactions and long-term processes in waste matrices;
- need for proven maintenance, repair and barrier-strengthening measures;
- uncertainty regarding the applicability of available technical solutions in existing facilities;
- degradation of concrete and other materials, including processes such as alkali-silica reaction;
- need to address specific problematic waste forms or scenarios;

- risk of reduced containment performance if ageing is not managed effectively.

3.3.4.3 Proposed next research steps

- collection and analysis of practical cases, including what happened, what measures were taken and how successful they were;
- development of a database or state-of-the-art overview of available technical solutions;
- targeted R&D for specific problematic waste scenarios, such as highly activated PVC;
- further research on concrete degradation and long-term ageing processes, including alkali-silica reaction;
- development and testing of corrosion-resistant and more durable materials;
- development of applicable overpacking and storage-condition improvement solutions;
- improved understanding of radionuclide transport in ageing materials to support ageing management programmes.

3.3.4.4 Stakeholders

The work should involve WMOs/operators (practical needs, facility-specific experience and implementation feedback), REs (testing, technology development and assessment of material performance), regulators and TSOs (applicability framework and safety expectations for using such measures) and, where relevant, CSOs (transparency, access to information and independent confidence that safety is not reduced).

3.3.4.5 Expected benefits and impact:

- better identification of practical solutions for ageing management;
- improved preparedness to address degradation of packages, barriers and structures;
- extended safe operation of storage facilities;
- reduced probability of loss of containment;
- improved accessibility and manageability of waste packages;
- stronger basis for updating ageing management programmes.

3.3.4.6 Indicative timeframe

Participants considered that the collection of existing cases and identification of available solutions should start in the short term. Development, testing and implementation of technical measures for barrier strengthening and material durability may require a 3-5 year timeframe.

3.3.5 Topic 5: Retrievability and repacking under degraded conditions

No specific breakout group outputs provided for topic 5.

3.3.6 Topic 6: Waste Acceptance Criteria (WAC) evolution and bridging methods

3.3.6.1 Context and technical challenge

Participants noted that radioactive waste and waste packages may change during extended storage, while future disposal requirements, including Waste Acceptance Criteria, may also evolve. This creates a risk that waste stored today may not meet future disposal acceptance requirements without additional treatment, conditioning or repackaging. The main challenge is therefore to develop approaches that can bridge current storage conditions with future disposal needs and reduce the risk of late-stage non-compliance.

3.3.6.2 Key identified gaps:

- radioactive waste may change over long storage periods radiologically, chemically and physically;
- future Waste Acceptance Criteria may differ from the assumptions used when waste was originally packaged or stored;
- uncertainty remains regarding radionuclide behaviour and waste matrix evolution during extended storage;
- additional conditioning or repackaging may be needed at a late stage;
- Waste Acceptance Criteria - related aspects may be particularly important for future shared disposal facilities.

3.3.6.3 Proposed next research steps

- research on existing and new waste streams to assess their compatibility with future disposal routes;
- chemical research on radionuclide behaviour during long-term storage;
- assessment of how waste packages may evolve over time and how this could affect future acceptance;
- development of bridging approaches between current storage conditions and future Waste Acceptance Criteria;
- research on possible Waste Acceptance Criteria approaches for shared disposal facilities.

3.3.6.4 Stakeholders

This topic should involve WMOs/operators (information on waste packages, storage history and practical constraints), REs (research on waste behaviour and radionuclide processes), regulators and TSOs (development of safety expectations, Waste Acceptance Criteria-related approaches and criteria for demonstrating future acceptability).

3.3.6.5 Expected benefits and impact:

- reduced risk of future non-compliance with disposal requirements;
- better understanding of how waste and packages evolve during extended storage;
- improved preparedness for future disposal or transfer to shared facilities;
- reduced need for late-stage conditioning or repackaging;
- more efficient planning of storage, retrieval and disposal activities;
- time savings and improved confidence that waste can be disposed of properly.

3.3.6.6 Indicative timeframe

Participants suggested that work on this topic should start within 1-3 years. Since the evolution of waste packages, Waste Acceptance Criteria and disposal routes may require longer-term research and validation, the overall duration of activities may extend beyond 3 years.

3.3.7 Topic 7: External impacts and climate resilience for extended storage

No specific breakout group outputs provided for topic 7.

3.3.8 Topic 8: Emerging waste streams

3.3.8.1 Context and technical challenge

Participants discussed emerging waste streams in the broader context of new reactor and fuel types, research reactors and other nuclear installations. Such waste may not fully fit existing storage, treatment, conditioning or disposal assumptions. There is uncertainty about future waste volumes, properties and suitable management routes. The main challenge is therefore to anticipate these waste streams early enough to ensure that appropriate storage and disposal options are available before the waste becomes a practical problem.

3.3.8.2 Key identified gaps:

- uncertainty regarding the origin, volume and characteristics of future radioactive waste streams;
- potential mismatch between new waste types and existing storage infrastructure;
- need for sufficient capacity for storage and disposal of emerging waste streams;
- changing procedures and management assumptions at facilities;
- limited data on the properties and behaviour of new types of waste.

3.3.8.3 Proposed next research steps

- characterisation of future and emerging radioactive waste streams;
- collection of data on the properties, volumes and expected behaviour of new waste types;
- assessment of suitable treatment, storage and conditioning options;
- evaluation of whether existing infrastructure and procedures are adequate for these waste streams;
- early development of management routes before waste accumulation becomes problematic.

3.3.8.4 Stakeholders

The topic should involve operators (information on expected waste generation, costs and facility constraints), REs (characterisation studies and assessment of treatment or conditioning options) and TSOs (safety assessment, regulatory support and evaluation of whether proposed management routes are adequate for long-term storage and disposal).

3.3.8.5 Expected benefits and impact:

- better preparedness for managing new and emerging radioactive waste streams;
- early identification of suitable storage, treatment, conditioning and disposal options;
- reduced risk that future waste will become difficult to manage due to lack of planning;
- improved understanding of the data needed for safety assessment and decision-making;
- better alignment between future waste generation and available infrastructure.

3.3.8.6 Indicative timeframe

Participants suggested a 3-5 year timeframe for this topic. This period would allow for initial characterisation, collection of relevant data and assessment of suitable treatment, storage and conditioning options for emerging waste streams.

3.3.9 Topic 9: Social science and humanities (stewardship)

3.3.9.1 Context and technical challenge

Participants emphasised that long-term storage is not only a technical issue, but also raises questions of trust, fairness, transparency and responsibility across generations. When storage is extended over long periods, there is a risk of misunderstanding or underestimation of the societal implications. Civil society concerns may relate to access to information, public involvement, security risks and the possibility that storage becomes "long-term by default" without clear decisions or accountability.

3.3.9.2 Key identified gaps:

- risk of misunderstanding or underestimation of long-term storage issues;
- need for clearer communication on safety, responsibilities and decision-making;
- limited practical models for public involvement during extended storage;
- need to address legal, environmental and social aspects together with technical issues;
- concerns about fairness, intergenerational responsibility and long-term public trust.

3.3.9.3 Proposed next research steps

- integration of nuclear and environmental law aspects into long-term storage discussions;
- study of practical public involvement models;
- testing of approaches for stakeholder engagement in extended storage decisions;
- analysis of how information should be shared with the public over long periods;
- development of approaches to support trust, transparency and accountability.

3.3.9.4 Stakeholders

This topic should involve regulators and TSOs (open technical discussions and provide understandable information on safety issues and possible solutions), decision-makers (address the legal, financial and institutional framework) and civil society actors (identifying concerns, expectations and conditions for meaningful involvement and trust-building).

3.3.9.5 Expected benefits and impact:

- improved understanding of societal expectations and concerns;
- stronger transparency and public confidence in long-term storage decisions;
- more practical models for public involvement;
- better integration of legal, environmental, technical and social dimensions;
- reduced risk that extended storage is perceived as unmanaged or becoming permanent by default;
- improved basis for fair and accountable decision-making over long periods.

3.3.9.6 Indicative timeframe

No specific timeframe was defined during the discussion.

3.4 Summary of the workshop

As an integral part of Subtask 3.2, a dedicated workshop was organised to support the discussion of radioactive waste management strategies for situations where storage extends beyond, or has already exceeded, the original design lifetime of storage facilities and/or waste packages. The workshop built on the survey analysis and on the findings reported in Milestone 38 [4], with the aim of moving from the general identification of challenges towards more specific and prioritised R&D recommendations.

The workshop was structured around nine pre-identified challenge topics related to long-term and extended storage. These topics covered lifetime definition and decision points, ageing management tools, predictive and probabilistic approaches, technical solutions for barrier strengthening, retrievability and repacking, Waste Acceptance Criteria evolution, external impacts and climate resilience, emerging waste streams, and social science and humanities aspects. To facilitate more focused discussion, participants were divided into four breakout groups. Each group selected three topics for detailed consideration and was invited to identify the core problem, possible R&D steps, relevant actors and expected impact. All proposed topics, except retrievability and repacking under degraded conditions and external impacts and climate resilience, were selected by at least one group and discussed during the breakout sessions. The discussions confirmed that many challenges are closely interlinked. For example, decisions on lifetime extension depend not only on regulatory criteria, but also on the availability and quality of historical data, the condition of packages and structures, ageing management tools, predictive models, future Waste Acceptance Criteria, funding and stakeholder confidence.

A recurring message from the workshop was the need for practical and usable tools rather than only high-level concepts. Participants highlighted the importance of digitalising and recovering historical information, developing simple modelling and assessment tools, improving monitoring and inspection methods, establishing databases on waste packages and degradation mechanisms, and benchmarking existing approaches. These tools are needed to support timely and risk-informed decisions on continued storage, upgrading, retrieval, repackaging or closure.

The workshop also underlined the importance of understanding and managing ageing processes. Participants identified the need for better characterisation of facility and package condition, long-term experiments on drum ageing, research on corrosion and material durability, improved understanding of radionuclide transport in ageing materials, and practical technical solutions for maintenance, repair, overpacking and barrier strengthening. Such work would help operators move from detecting ageing to implementing effective and realistic corrective measures.

Forward-looking issues were also discussed. Participants noted that waste packages may change over time while future Waste Acceptance Criteria may evolve, creating a risk of late-stage non-compliance with disposal requirements. Emerging waste streams, including those linked to new reactor and fuel technologies, were also considered important, as they may not fit existing storage, treatment or disposal assumptions. Early characterisation, data collection and assessment of suitable management routes were therefore identified as important areas for further work.

The social dimension of extended storage was recognised as an important part of the overall challenge. Participants noted that long-term storage raises questions of transparency, trust, public involvement, fairness and intergenerational responsibility. The need to study and test practical public involvement models, and to better integrate nuclear and environmental law aspects, was highlighted as a way to support more credible and accountable decision-making.

Overall, the workshop provided a useful platform for translating survey findings into more concrete R&D needs. The main outcomes point to the need for improved decision criteria, better ageing management and predictive tools, practical technical solutions, stronger data systems, early planning for future waste streams, and more structured stakeholder involvement.

4. Summary and outcomes

Task 3 of the ASTRA WP was initiated to evaluate alternative management strategies for RW stored in facilities operating beyond their original design lifetimes. While Subtask 3.1 (MS 38) established the foundational baseline – mapping facility counts, broad reasons for extensions, data preservation practices, and public transparency – Subtask 3.2 (MS 60) transitions the focus to a detailed technical and strategic evaluation. This report provides an in-depth analysis of specific facility characteristics, safety reassessments, future economic strategies, and actionable R&D pathways.

The facility profiles and waste characteristics analysed in MS60 confirm a considerable diversity of stored waste inventories, storage concepts and national management approaches. This diversity is influenced not only by whether a country can be considered a LIMS or a SIMS, but also by the maturity of the national waste management programme, the availability of disposal routes, the age of facilities, and the completeness of historical records. Applied storage methods range from standardised containerised storage (using metal drums, concrete matrices, and specialised high-integrity casks) to bulk storage in silos, liquid waste tanks, and well-type near-surface storage for SRS.

Safety reassessments, risks and hazards identified in the country analyses show that, in many cases, radiation impacts during normal operation remain within regulatory limits. However, extended storage brings a broader set of safety concerns that cannot be reduced only to radiological impact during normal operation. Physical degradation of engineered barriers is a recurrent issue, including corrosion of metallic containers, cracking or ageing of concrete structures, and degradation of specific waste or package materials, such as PVC components in historical waste. Safety assessments also consider external natural and man-made hazards, including aircraft crash scenarios, flooding, seismic events, fire, groundwater-related impacts and, in some cases, tsunami or extreme weather-related scenarios.

Alongside physical degradation, the quality and preservation of inventory data remain a critical cross-cutting issue. Missing, incomplete or non-uniform historical records, especially for legacy waste and waste packaged before modern inventory systems were introduced, complicate safety assessments, retrieval planning, repackaging, and future disposal preparation. The analysis shows that these packages may require additional verification, re-characterisation or documentation recovery before further management decisions can be taken.

The urgency of retrieval and future management actions varies significantly between facilities and countries. Importantly, retrieval urgency does not always directly correspond to the overall risk ranking. In several cases, facilities are ranked as low risk under current conditions, but retrieval or repackaging may still be required within a shorter timeframe due to licence conditions, inspection results, capacity constraints or strategic planning needs. Some facilities require action within 5 years due to uncertainties in inventory, repackaging needs, capacity limitations or inspection outcomes. Other facilities fall within a medium-term timeframe of 5 to 15 years, where corrective actions, remediation, dismantling preparation or retrieval planning are needed. Facilities with stable conditions, adequate safety margins or continued regulatory control may defer retrieval for more than 15 years, often linked to the future availability of disposal routes.

To manage these timelines, Member States are applying or considering several types of future strategies:

- continued operation through licence renewal, relicensing or periodic safety reassessment, particularly where disposal routes are not yet available;
- facility upgrades, extensions or improvements to support safe storage over longer periods;
- waste retrieval, reconditioning and repackaging campaigns, especially for historical waste, degrading packages or waste that needs to be prepared for disposal;
- relocation to new or improved storage areas where this is part of the national strategy;
- closure planning, decommissioning preparation or transfer to future disposal facilities, where such routes are defined.

The analysis also shows that some options, such as recycling, reprocessing, clearance or reuse, are applied only in specific national contexts and are not generally available across all programmes. In several countries, long-term strategies remain dependent on the future availability of final disposal facilities, while in others no detailed public information on future approaches or timescales is available.

The economic viability of these long-term strategies depends on different funding models. Countries with large nuclear power programmes often rely on dedicated funds or financial mechanisms based on the polluter-pays principle, while several SIMS or legacy-focused programmes rely primarily on government budgets. Mixed models also exist, combining state funding, industry contributions and, in some cases, international grants. Cost estimation maturity varies widely: some countries have specific estimates for facility extension, repository construction, closure or remediation, while others report that costs have not yet been calculated or are not publicly available. This uneven level of financial planning creates uncertainty for long-term retrieval, repackaging, closure and disposal strategies.

A dedicated multi-stakeholder workshop successfully transitioned the Task 3 discourse from diagnosing vulnerabilities to mapping R&D pathways. Participants forged a strong consensus on the urgent need, generally within the next 1 to 5 years, to develop:

- practical ageing management tools, including non-destructive on-site monitoring techniques to assess package and barrier conditions without breaching containment;
- predictive tools, shared databases and modelling approaches to support forecasting of package, matrix and barrier evolution;
- technical measures to maintain safety functions, including improved overpacks, corrosion-resistant materials, barrier strengthening and environmental control;
- better recovery, digitalisation and preservation of historical data to support safety assessment, transparency and future decision-making;
- clearer operational thresholds and decision gates for continued storage, repackaging, retrieval or transfer to disposal.

Ultimately, MS 60 establishes that continuing to rely on incremental, step-by-step storage extensions without a shared strategic framework risk locking Member States into reactive, costly decisions while transferring unresolved burdens to future generations. The technical findings and collaborative R&D roadmaps presented herein directly inform the ASTRA White Paper, calling for a shift toward proactive, evidence-based management and the European development of a "next-generation decision-support framework" for end-of-life storage.

5. References

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Appendix 1 Agenda of the Task 3 Workshop #2

Astra

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WP3 ASTRA
TASK 3 WORKSHOP 2
AGENDA

Teams meeting 23rd January 2026 09:00-12:30 CET

Link to the meeting: **Microsoft Teams** Join teams meeting here

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Start time	Topic	Speakers
09:00-09:10	Welcome and objectives	Kateryna Fuzik & Wilfried Pfingsten
09:10-09:45	Follow-up from Workshop 1: developments and key outputs • Milestone 38 (key findings and messages) (15') • Deliverable 3.1 Green Paper (scope and identified problematics for Task 3) (10') • Civil society perspective (key issues and expectations) (10')	Kateryna Fuzik & Wilfried Pfingsten & Task 6 representative
09:45-09:55	Introductory guide for interactive breakout sessions	Kateryna Fuzik
09:55-10:05	Q&A Session: Open floor for questions and clarifications	Wilfried Pfingsten & All
	Photo of participants	All
10:10-10:20	Coffee Break	
10:20-11:20	Interactive breakout sessions	Moderators & All (in groups)
11:20-11:30	Coffee Break	

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ASTRA WP Task 3 Workshop 2 Agenda

Start time	Topic	Speakers
11:30-12:00	Short wrap-up from breakout groups	Moderators & All
12:00-12:10	Interactive Blitz Poll	Yevheniia Kudriashova & All
12:10-12:15	EURAD-2 2nd wave proposal from Task 3	Wilfried Pfingsten
12:15-12:20	Conclusions of workshop, next steps & closing remarks	Kateryna Fuzik