Milestone 70: Management strategies for small amounts of waste in SIMS

Work Package 3

10.5281/zenodo.19328384

Co-funded by the European Union under Grant Agreement n°101166718

Date of issue of this report: 30/03/2026

Document information

Project Acronym	**EURAD-2**
Project Title	**European Partnership on Radioactive Waste Management-2**
EC grant agreement No.	**101166718**
Work Package Title	**Alternative RWM Strategies**
Milestone No.	**70**
Milestone Title	**Management strategies for small amounts of waste in SIMS**
Lead Beneficiary	**EIMV**
Contractual Delivery Date	**March 2026**
Actual Delivery Date	**March 2026**
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Acknowledgement

This document is a milestone of the European Partnership on Radioactive Waste Management 2 (EURAD-2). EURAD-2 is co-funded by the European Union under Grant Agreement N° 101166718.

Executive Summary

The ASTRA Work Package (Alternative RWM STRAtegies) is a strategic study within the European Joint Programme on Radioactive Waste Management (EURAD-2). Its main objective is to investigate alternative radioactive waste management strategies, focusing on small and challenging waste streams (SIMS) as well as larger national programmes, in order to identify readiness, feasibility, and optimisation opportunities.

Analysis of Management Strategies for Small Amounts of Waste – ASTRA Task 5.1

The objective of ASTRA Task 5.1 is to create a community of practice including SIMS and LIMS to share predisposal and disposal strategies, aiming at cost effective RWM solutions targeting SIMS. The contextual topics for exchange have been specified by implementing a questionnaire to identify most pressing topics in need of targeted solutions. The community of practice has been implemented in form of live discussion forums.

Questionnaire. The questionnaire developed in Task 5.1 aimed at identifying urgent issues for cooperation and knowledge exchange between SIMS and LIMS. To this aim, representatives from both SIMS and LIMS countries indicated for each waste management step and each challenging waste, as defined in EURAD ROUTES WP [1], if for that waste type at this step a necessity of knowledge exchange exists. The evaluation of the answers indicate that the most pressing issues are related to the waste category of previously conditioned wastes, i.e. legacy waste in need of reprocessing. These high-ranked topics have been selected for Live Discussion Forums (LDFs). Interestingly, the rating schemes of SIMS and LIMS representatives show only slight diversions. Only five topics (Characterisation of metals and U/Ra/Th bearing wastes – Treatment of metals – Interim Storage of sludges and concrete) show significant differences in ranking between SIMS and LIMS representatives, being more often classified as important by LIMS than by SIMS.

Each LDF already executed is summarised in the next paragraphs.

LDF No. 1: Initial Inventory – Conditioned Waste. Reliable inventories are a prerequisite for safe waste management but are often incomplete or outdated, especially for historical and emergency waste. Good practices from several EU countries demonstrate the value of transparent data management, early stakeholder involvement, and long-term inventory maintenance.

LDF No. 2: Characterization – Conditioned Waste. Case studies from the Netherlands and Austria illustrate effective approaches to characterizing historical and conditioned waste using a combination of archival data, non-destructive techniques, and standardized radioactive waste. Dedicated tools, structured databases, and clear interim storage acceptance criteria significantly improve safety and traceability.

LDF No. 3: Treatment – Conditioned Waste. The Swedish experience shows that volume reduction, stabilization, and concrete conditioning can produce waste forms suitable for long-term interim storage, even for diverse waste streams. Robust interim storage facilities remain essential in the absence of final disposal solutions.

LDF No. 4: Conditioning Methods – Conditioned Waste. Ukraine's graded approach to managing large volumes of emergency and legacy waste demonstrates how risk-based prioritization and phased remediation can deliver safety improvements when full remediation is not immediately feasible. Pilot projects confirm the value of conservative dose criteria, international benchmarking, and iterative safety assessments.

LDF No. 5: Impact of Definition of SIMS. SIMS typically generate small volumes of low- and intermediate-level waste from medicine, research, and industry. The report confirms that scaled-down versions of disposal concepts for large inventories are not cost-effective for SIMS. Instead, shared solutions, harmonized approaches, and EU-supported demonstrator projects are needed to reduce costs and risks for the treatment of small amounts of radioactive waste.

LDF No. 6: Waste Acceptance Criteria – Conditioned Waste. The waste acceptance procedure and interim storage facilities of the Netherlands have been presented. The waste is stored on the COVRA site depending on the waste class LILW (Cat. A to D and NORM) or HLW, and regularly monitored, before being placed in a disposal facility. Decision on disposal concept(s) is expected 2050.

Investigation of Shared Solutions for Different Radioactive Wastes – ASTRA Task 5.2

ASTRA Task 5.2 investigates the potential for shared solutions in radioactive waste management across Europe, addressing both predisposal and disposal activities, including mobile solutions, governance aspects, and long-term sustainability of expertise. The Task 5.2 builds on the outcomes of EURAD-1 WP ROUTES and ERDO Association work and complements Task 5.1 by focusing on multinational cooperation mechanisms and strategic enablers for shared infrastructure.

The analysis presented in this document is based on a structured questionnaire (26 questions) and three dedicated workshops. In total, 24 responses from 17 countries on the questionnaire were received, representing Research Entities (RE), Waste Management Organisations (WMO), Technical Support Organisations (TSO), Civil Society (CS), and Industry. More than 80 % of respondents confirmed that their country generates radioactive waste and/or spent fuel requiring deep geological disposal (DGR), underlining the broad European relevance of investigating shared or multinational disposal options.

Despite this common long-term need, only 29 % of organisations reported existing collaboration in sharing radioactive waste management (RWM) activities or facilities, while 62.5 % indicated no formalised cooperation. This highlights substantial available potential for collaboration.

The primary drivers for cooperation are technical, financial, and safety-related considerations. Knowledge exchange and training are identified as key cooperation areas by approximately 90 % of respondents, followed by maintenance of specialist competences (around 73 %) and pooling of resources for early-stage generic studies (around 60 %). Interest in shared disposal facilities is expressed by 41 % of respondents, with significantly stronger support for shared geological disposal (87 % of those interested in shared disposal) than for near-surface solutions (67 %).

Regarding national strategies, 37.5 % of respondents indicated that their country considers a dual-track approach (parallel national and multinational pathways), while 50 % do not. Among dual-track countries, 80 % show interest in shared geological disposal. This demonstrates that shared solutions are increasingly viewed as a strategic risk-management instrument, preserving flexibility under long implementation timelines and political uncertainty.

Legal frameworks remain heterogeneous. Half of respondents (50 %) report a legal ban on import of radioactive waste or spent fuel, while 33 % indicate a ban on export. Divergences in responses from the same country and discrepancies with official submissions (around 20 % of cases) reveal governance complexity and underline the need for legislative clarity and harmonisation as a precondition for multinational implementation.

Joint technical development of disposal concepts receives significant support. 58 % of organisations express interest in contributing to generic DGR designs, safety case development, and harmonisation of costing methodologies. Generic safety case preparation and post-closure assessment are particularly emphasised, especially by smaller or newcomer countries seeking to avoid duplication of effort and to strengthen national programmes through shared methodologies.

Deep Borehole Disposal (DBD) receives even stronger alignment, with 71 % of respondents recognising DBD as a potential future shared disposal option. Inventories considered potentially suitable include spent nuclear fuel (SNF), vitrified high-level waste (HLW), long-lived intermediate-level waste (ILW), sealed sources, and research reactor fuel. However, respondents stress that DBD requires further technical maturation, operational demonstration, and robust long-term safety case development before full implementation.

Half of the organisations (50 %) express willingness to collaborate in developing stakeholder engagement under consent-based siting for shared solutions. Governance and societal aspects are consistently identified as decisive enabling factors. The most frequently selected issues concern: defining who should be involved in site selection and decision-making, establishing minimal site selection standards, applying harmonised safety and security requirements, and ensuring effective public participation. Transboundary participation mechanisms consistent with Aarhus and Espoo principles are considered essential in a multinational context.

The emergence of Small Modular Reactor (SMR) and Advanced Reactor programmes in 63 % of responding countries adds a forward-looking dimension. A majority (54 %) agree that widespread SMR deployment could increase the need for regional or shared RWM solutions, particularly to avoid infrastructure duplication and improve economies of scale.

In summary, Task 5.2 demonstrates that shared solutions are technically feasible and strategically relevant for a substantial portion of European programmes. However, governance alignment, regulatory harmonisation, societal acceptance, and legal clarity are as critical as technical feasibility. The task provides a structured, quantified overview of European stakeholder positions, identifies priority cooperation areas - particularly safety case harmonisation, costing methodologies, and knowledge exchange - and establishes a foundation for future demonstrator projects and policy dialogue within EURAD-2.

Keywords

Radioactive waste, Management of radioactive waste, Small amount of waste, Challenging waste, Shared solutions, Small inventory member states

Table of content

1. PART 1 – ASTRA Task 5.1: Analysis of Management Strategies for Small Amounts of Waste

1.1 Introduction

The objective of ASTRA Task 5.1 is to create a community of practice including SIMS and LIMS to share predisposal and disposal strategies, aiming at cost effective RWM solutions targeting SIMS. The contextual topics for exchange have been specified by implementing a questionnaire to identify most pressing topics in need of targeted solutions. The community of practice has been implemented in form of live discussion forums.

1.2 Methodology

Subtask 5.1 of the ASTRA work package investigates the status quo of management strategies for small amounts of waste in the member states participating in this task. The member states can be differentiated by the amount of radioactive waste they have to manage, generally dividing between so-called small inventory member states (SIMS) and so-called large inventory member states (LIMS). Both categories of member states were represented in this task and provided input to the analysis. In total, 14 countries provided input, of which seven are classified as SIMS (Austria, Bulgaria, Denmark, Estonia, Netherlands, Poland, Portugal) and seven are classified as LIMS (Czech Republic, Finland, France, Germany, Slovenia, Switzerland, Ukraine).

To the objective of identifying gaps, country-specific areas of interest were collected from country representatives via a questionnaire. A special focus has been laid on identifying topics of increased interest, e.g., due to a lack of current solutions or best practices. Following the identification of areas, specific topics were further elaborated in workshops and live discussion forums.

Questionnaire. The questionnaire aimed at identifying topics of interest for further discussion in the LDFs. Based on the work done in EURAD ROUTES [1, 2, 3], the questionnaire covered the predisposal and disposal steps. These were: Initial waste inventory, characterization, treatment, conditioning, interim storage solutions, development of WAC, and scalable disposal solutions. For each of the steps, the interesting waste types should be given. The template of the questionnaire is shown in **Erreur ! Source du renvoi introuvable.**.

Workshops. The workshops were organized jointly by all three subtasks of ASTRA Task 5. In total, three workshops in month 8 (M8), month 12 (M12) and month 14 (M14) were realized to discuss the preliminary results of each subtask. Regarding Subtask 5.1, during the workshops the topics and results of the past LDFs were shared.

Live Discussion Forums (LDFs). The monthly LDFs were initiated by Task 5.1. The aim is to provide a platform for discussions with waste management experts from different countries, presenting their challenges and best practices to initiate a discussion amount the audience. Each live discussion forum covers a specific topic, derived from the results of the questionnaire. The order of topics covered by LDFs has been selected based on the ranking of topics in the questionnaire responses.

The results of each activity are presented and analysed in this report. Derived R&D recommendations will be published in Deliverable D3.2 [4] and will only be addressed briefly in this report.

1.3 Results of the Questionnaire – Overview

The questionnaire compiled 12 questions to elaborate the necessities of open discussion / cooperation on specific waste types and specific waste management steps. In total, fourteen representatives have submitted their response, representing seven SIMS and seven LIMS:

Analysing the individual responses, topics could be identified to provide a discussion forum for on a high priority. Plotting all answers in a heat map like fashion, the answers looked as shown in *Figure 1*.

n [%]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100

	SUM [%]										
	Predisposal					Disposal					
Waste types	Initial inventory	Characterisation	Treatment	Conditioning methods	Interim storage	WAC	Scalable disposal	WMO	TSO	RE	CS
Sludge	30-40	30-40	30-40	40-50	30-40	30-40	20-30	40-50	40-50	30-40	40-50
Organics	50-60	50-60	50-60	50-60	50-60	40-50	30-40	50-60	60-70	40-50	40-50
Concrete	50-60	50-60	40-50	40-50	40-50	40-50	40-50	50-60	40-50	60-70	40-50
Metals	50-60	60-70	50-60	40-50	50-60	50-60	40-50	40-50	40-50	70-80	90-100
DSRS	60-70	40-50	50-60	40-50	50-60	40-50	30-40	60-70	40-50	60-70	40-50
SIERs	50-60	50-60	50-60	60-70	50-60	40-50	20-30	20-30	60-70	70-80	40-50
U/Ra/Th	50-60	40-50	50-60	60-70	50-60	40-50	30-40	40-50	50-60	60-70	90-100
Graphite	50-60	40-50	50-60	50-60	50-60	40-50	40-50	60-70	30-40	60-70	40-50
Other	10-20	0-10	0-10	0-10	0-10	10-20	0-10	0-10	0-10	0-10	40-50
Waste cathegories	Initial inventory	Characterisation	Treatment	Conditioning methods	Interim storage	WAC	Scalable disposal	WMO	TSO	RE	CS
Conditioned (e.g. bitumized)	80-90	70-80	70-80	70-80	60-70	60-70	60-70	60-70	80-90	90-100	0-10
Legacy waste	60-70	60-70	60-70	50-60	50-60	50-60	50-60	40-50	50-60	60-70	90-100
Hazardous waste	10-20	10-20	20-30	20-30	20-30	20-30	20-30	50-60	0-10	10-20	0-10
Other	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10	0-10

	Predisposal					Disposal	
	Initial inventory	Characterisation	Treatment	Conditioning methods	Interim storage	WAC	Scalable disposal
WMO	40-50	30-40	40-50	40-50	30-40	50-60	40-50
TSO	50-60	50-60	50-60	40-50	30-40	30-40	20-30
RE	50-60	50-60	50-60	50-60	50-60	40-50	30-40
CS	20-30	20-30	20-30	20-30	60-70	70-80	70-80

Figure 1 - Heat Map presenting the outcome of the questionnaire. On the table on the right side, the responses by college (WMO – Waste Management Organisation, TSO – Technical Support Organisation, RE – Research Entity, CS – Civil Society) are shown.

The responses to the questionnaire revealed a clear preference for the topic to be tackled first. Topics that have already been discussed in LDFs are presented in this report. Further topics will be discussed in LDFs following the publication of this milestone.

Analysing each field independently, it is interesting to highlight that most topics have been ranked equally from SIMS and LIMS. Only five topics have shown a significant difference in rating between SIMS and LIMS, meaning the results differ by at least 200 %. These topics are:

- Predisposal step of "Characterisation" for waste type "Metals"
- Predisposal step of "Characterisation" for waste type "U/Ra/Th bearing wastes"
- Predisposal step of "Treatment" for waste type "Metals"
- Predisposal step of "Interim Storage" for waste type "Sludges"
- Predisposal step of "Interim Storage" for waste type "Concrete"

All these five challenges have been more often classified as important by LIMS than by SIMS.

1.4 Results on "Initial Inventory – Conditioned Waste"

Aim of the very first LDF was the issue of reliable radioactive waste inventory data. LDF No. 1 emphasized persistent concerns regarding the identification, classification, and documentation of waste streams, particularly heterogeneous waste streams and sealed sources. The initial inventory is often influenced by several factors, such as incomplete historical records, a lack of clearly defined WAC hampering goal-oriented radionuclide characterisation, and inadequate or undocumented historic preconditioning or conditioning. This can result in legacy waste streams lacking characterization to a detail as needed to fulfil WAC. To circumvent this issue in the future, the value of structured databases and robust documentation practices has been highlighted, as good practices have demonstrated by experience in several countries.

From a SIMS perspective, the development of an initial inventory is often constrained by the following factors: the lack of a standardized, digitized, and transparent national database; limited human and financial resources for inventory updates and waste characterization; restricted access to international good practices; and fragmented or lost historical records. In the context of LIMS, the initial inventory poses several challenges, including the management of substantial and varied waste streams, the integration of multiple inventories from disparate waste producers, the retroactive application of standardized WAC, and the balancing of cost, dose optimization, and the level of detail required for recharacterizing historical waste.

In the context of establishing and improving the initial inventory of radioactive waste, several targeted solutions can be proposed to address existing gaps and challenges. A risk-based approach, graded according to severity, should be adopted for legacy and emergency-origin waste, with a focus on high-risk waste streams for detailed characterization to ensure that the initial inventory captures the most safety-relevant information. The utilization of a common EU-level platform or harmonized inventory structure, with the foundation being existing national exemplars, would serve to support consistency, comparability, and transparency of initial inventories across Member States.

To guarantee the initial inventory remains both accurate and usable over time, the implementation of modular digital inventory systems is essential. Addressing data gaps in historical and legacy waste requires investment in retrospective digitization projects, i.e. supported by EU funding instruments, to recover and structure still existing records. Finally, robust and redundant data security measures, including off-grid backups and secure digital archives, are essential to safeguard initial inventory data and ensure its long-term availability and integrity.

1.5 Results on “Characterisation – Conditioned Waste”

Representatives from *Nuclear Research and consultancy Group* (NRG is called NRG PALLAS since 2025) from the Netherlands and *Nuclear Engineering Seibersdorf GmbH* (NES) from Austria presented approaches, highlighting good practices, gaps, capacity needs, and expectations for the second wave of EURAD-2 funding, including pilot demonstrations, methodological support, and networking.

NRG PALLAS, The Netherlands. For over sixty years, radioactive waste from the Petten research site and other Dutch institutions was stored at the on-site Waste Storage Facility (WSF). After the creation of the national waste organization COVRA in 1984 and its relocation to Nieuwdorp, much waste was transferred to COVRA, but significant low- and intermediate-level waste remained in Petten: so-called legacy waste. Following the opening of COVRA’s High Activity Treatment and Storage Building (HABOG) facility in 2003, NRG launched several Radioactive Waste Projects (latest called RAP) to prepare the historical waste remaining at Petten for transfer to Nieuwdorp. As the legacy waste did not meet modern acceptance criteria, the project focused on developing specialized equipment, adapting laboratories at Petten, and arranging certified transport solutions. In 2011, NRG started the preparations of classifying the different waste streams by setting up characterization strategies, sorting and packaging on site in Petten for the transport to COVRA. Up to 2023, most low-level waste has been transported to COVRA and intermediate level waste is still temporarily stored in the WSF ready and awaiting packaging in a dedicated facility called the Waste Transfer Unit (WTU) before it can be transported. This is because COVRA started to build a new storage facility, called the MOG (Multi-functional Storage Building) in 2023 for low and intermediate level waste which is expected to be opened in 2026. NRG PALLAS and COVRA are now collaborating to use the MOG when ready for storage of the intermediate level legacy waste streams.

To meet regulatory safety requirements, archival data are combined with new nuclide calculations and gamma measurements to characterize historical solid radioactive waste at Petten. The waste is sorted into two activity-based categories – low, and – intermediate each following specific treatment and storage routes. A key challenge is the segregation, characterization, conditioning and packaging of individual containers, addressed by dividing the waste into smaller, well-defined “waste families” with similar materials and irradiation histories, in line with IAEA recommendations [5].

NRG PALLAS has developed different tools for segregating and characterizing radioactive waste, such as the VINISH or HIRARCHI. VINISH (Visual Inspection and Nuclide Identification System) is a gamma scanning device for high-level radioactive waste [6]. It measures vertical “slices” of rotated historic waste canisters using a high-purity germanium detector to identify nuclides and their activities. Designed for activities up to 10 TBq Co-60, it still requires adjustments for very high-dose vessels. VINISH is also used after repacking to generate legally required nuclide and activity lists for transport and storage

[**Erreur ! Signet non défini.**]. HIRARCHI (HIgh Radioactive Raw waste Characterization and Identification) is a sorting system in NRG PALLAS's hot cell facility [7]. It uses a movable gamma detector and camera to scan historic waste spread on a platform within a containment ring. The Co-60 response is converted into colored "isoplots" that indicate different waste categories for characterization and sorting [**Erreur ! Signet non défini.**].

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To meet regulatory safety requirements, archival data are combined with new nuclide calculations and gamma measurements to characterize historical solid radioactive waste at Petten. The waste is sorted into three activity-based categories – low, intermediate-low, and intermediate-high – each following specific treatment and storage routes. A key challenge is the segregation, characterization, and packaging of individual containers, addressed by dividing the waste into smaller, well-defined "waste families" with similar materials and irradiation histories, in line with IAEA recommendations [9].

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Nuclear Engineering Seibersdorf GmbH, Austria. The Seibersdorf site has stored Austria's radioactive waste since the late 1960s. Interim storage is currently operated by Nuclear Engineering Seibersdorf until 2045, due to delays in establishing a final disposal facility. Austria has no nuclear power plants or high-level waste, only generating low- and intermediate-level waste, most of which is short-lived (>97%).

Following the extension of the interim storage period to 2045, a new storage concept was developed which requires older waste packages to be reconditioned, documentation to be updated and individual inspections of the waste drums to be enabled. Reconditioning of legacy waste allows for comprehensive characterization, including visual inspection and laboratory-based analyses of collected samples (e.g., XRF). At the same time, efforts are made to minimize the waste (e.g. through incineration or high-pressure compaction).

As Austria lacks waste acceptance criteria (WAC) for disposal, NES has established explicit and detailed WAC for the interim storage facility. These criteria focus on safety, long-term stability and flexibility for future disposal options, and mainly use standardized 200-litre drums. Conditioned waste is generally dried before storage to reduce the risk of subsequent chemical reactions or corrosion [10].

The NES interim storage facility has defined acceptance criteria that specify the permitted types of drum, including those containing high-force compacted pellets, those containing homogeneously cemented waste, those containing ash (in stainless steel cartridges) and those containing disused sealed radioactive sources (DSRS) with appropriate shielding. The criteria also set limits on mass, activity inventory, dose rate and chemical characteristics. Compliance is verified upon receipt of waste using a dual control system [**Erreur ! Signet non défini.**].

1.6 Results on "Treatment – Conditioned Waste"

A representative from Svensk Vattenfalls Avfallsbolag (SVAFO) in Sweden held a presentation during LDF No. 3 on the treatment of conditioned waste, and on the handling of past improper disposal in Sweden.

SVAFO operates under the Vattenfall group, which is owned by Forsmarks Kraftgrupp AB, OKG AB, and Ringhals AB. The company is responsible for the treatment of radioactive waste at Studsvik, including the storage of legacy waste, liquid waste, and the decommissioning of the R2/R2-0 research reactor, which was shut down in 2005. The facility treats solid and liquid intermediate waste, while the interim storage facility for low and intermediate level waste is used for operational waste from the Studsvik facilities. This includes irradiated and contaminated material from the production of isotopes and fuel testing, and operational waste from waste handling, as well as some external waste, such as from hospitals or industry [11].

The facility treats intermediate solid and liquid waste from Studsvik by reducing volume, sorting, and stabilizing the waste. Solid waste is compacted, packed, and stabilized with concrete, while liquid waste is treated through sedimentation and then solidified using concrete. The treatment process generates waste forms that are suitable for storage or eventual disposal.

Once treatment has been completed, the waste is transferred to the interim storage facility designated for low and intermediate level waste. The interim storage facility, constructed in the 1980s, is designed for the temporary storage of radioactive waste from Studsvik and other external sources that have undergone conditioning. The facility is located within a bedrock cavern and is supported by engineered reinforcement, drainage, and monitoring systems. It has been designed to store waste until approximately 2045 [11].

1.7 Results on "Conditioning methods – Conditioned Waste"

During the LDF No.4, representatives from the State Scientific and Technical Center for Nuclear and Radiation Safety (SSTC NRS) from Ukraine presented on conditioning methods and remediation projects in Ukraine. The presentation addressed national frameworks, pilot projects, prioritisation, graded approaches, and international cooperation.

Ukraine has an estimated 2 million m^3 of emergency and legacy radioactive waste, largely resulting from the Chernobyl accident. Most of this waste is stored near where its place of origin, particularly within the Chernobyl Exclusion Zone (CEZ). Around the Chernobyl nuclear power plant, nine radioactive waste temporary localisation sites (RWTLS) cover about 12 km^2 and contain roughly 1,000 trenches and clamps, many lacking engineered containments. An additional 53 similar sites were created around CEZ hold waste from decontaminated settlements and equipment [12].

Other legacy radioactive waste originates from former Radon-type facilities and former Soviet military activities. Selecting effective remediation strategies is challenging due to the poor characterisation data and heterogeneity of the waste. Full removal and remediation of all sites in the short term is not feasible, especially as many are located in already contaminated areas. These factors necessitate a graded, methodological approach to managing and remediate emergency and legacy radioactive waste [**Erreur ! Signet non défini.**]. The graded approach involves limited initial characterisation of facilities to assess hazards and rank them by risk. Facilities are divided into three categories: those requiring urgent waste removal, those where removal can be delayed, and those where waste can safely remain in place. Priority is given to developing removal technologies and safety analyses for the highest-risk sites, while more detailed safety assessments and long-term safety measures are applied to lower-risk facilities based on their hazard level and expected lifetime [13].

After screening safety assessment and ranking according to the degree of hazard were performed for RWTLS in and around the CEZ, the RWTLS "Pisky-1" site was chosen as a pilot facility for remediation. It had no engineered containment barriers and covered an area of about 124 m², with an estimated waste volume of 187 m³. The waste trench was capped with up to 0.6 m of local sandy soil and surrounded by drainage ditches. Radiation surveys indicated that the waste consists mainly of construction debris and contaminated soil. [14]

International experience from Europe, Asia, and the USA [15] was reviewed to define remediation criteria for the RWTLS "Pisky-1" site. Based on comparable sites, a main remediation dose criterion of 100 µSv per year for post-remediation exposure was established, reflecting regional contamination levels and optimisation of waste disposal volumes. Using conservative assumptions, this dose limit led to a derived soil criterion of 1 Bq/g for Cs-137, which ensures human exposure remains within the selected dose criterion. Radioactive waste was removed in 25 cm layers, with each layer surveyed for hot spots that were removed and packaged separately. Excavated waste was bagged, characterised, and sorted based on gamma dose rate, with material exceeding remediation criteria sent to temporary radioactive waste storage. Post-remediation monitoring confirmed compliance with end-state criteria, showing low radiation levels and Cs-137 activity below established limits [**Erreur ! Signet non défini.**].

There are also several Military sites of former Soviet Union with legacy RW on the territory of Ukraine (Vakulenchuk, Tsybuleve, Delyatin, etc.).

A pilot project was implemented at one site (Vakulenchuk) under a NATO programme on remediation of a RW storage site in Ukraine. The storage facility consisted of reinforced concrete well. The preliminary assessments have indicated that facility stores disused sealed radioactive sources (DSRS) (alpha, beta, gamma and neutron emitters) that contain Co-60, Cs-137, Sr-90 and Pu-239 as well as sources with fast neutron (possibly Pu-Be). Little data on the characteristics of the RW was available.

The next former military site that was remediated in Ukraine: Tsybuleve. Remediation was again performed within a NATO programme. The storage consisted of three concrete cylinders (wells), each with an inner steel liner, that were buried in soil next to each other. Available information indicated that the cylinders store DSRS that contain Co-60, Cs-137, Sr-90 and Pu-239 as well as sources with fast neutron (possibly Pu-Be).

Sufficiently detailed radiation surveys of storage sites were performed (gamma radiation dose rate, neutron flux density, surface contamination, specific activities of radionuclides in soils, vegetation, etc.). At the same time, the absence of initial data resulted in the need to adopt a conservative approach for safety assurance purposes and in the organisation of field work. Taking into account the absence of the initial data about DSRS and their state and small volume of wells, it was decided to implement a conservative approach and define the DSRS and other materials contained in the wells, as well as the structure of wells, as RW. At the Vakulenchuk site, the upper soil layer with radioactively contaminated spots was also defined as RW.

The primary criterion for remediation of the storage sites was that the annual individual effective dose to humans who might reside in the future at or near the area of the cleaned-up storage site should not exceeding 10 µSv per year. Determination of optimised criteria for remediation of sites was considered, in particular, the existing radiation contamination of adjacent areas and the amount of RW that needs to be processed and disposed.

A graded approach applied in the remediation of the Vakulenchuk and Tsybuleve storage sites, consisting of site surveys, site preparation for remediation activities, RW removal, containerisation and transport, removal of the storage structure and then final remediation of the site. The well structure from the Vakulenchuk storage site was dismantled in parts with layered RW removal; well structures at the Tsybuleve storage site were transported to specialised storage facility without their fragmentation and RW removal.

Surveys of soils removed around the wells during their dismantling were performed. The results of soil surveys were compared to similar soil surveys in the storage site location area. A final survey of the sites included, as well as before remediation, detection of the gamma radiation dose rate and neutron flux density and surface contamination measurements to confirm that radiological hazards were removed. After confirmation, the measures for final remediation were implemented, including levelling of the site, backfilling of fertile soil and planting trees.

1.8 Results “Impact of Definition of SIMS”

The topic for LDF No. 5 has been selected due to ongoing political discussions and activities on European level, supporting SIMS in their effort on RWM. The topic thereby is not a derivative of the questionnaire but has been included due to requests from participating organisations.

Small Inventory Member States (SIMS) are countries with generally no nuclear power program or only a very limited number of nuclear power plants, resulting in small volumes of radioactive waste mainly from research reactors, medicine, industry, and research. In the EU, SIMS include Austria, Cyprus, Denmark, Greece, the Netherlands, Poland, Portugal, Slovenia, Croatia, Estonia, Ireland, Latvia, Luxembourg, and Malta.

SIMS commonly face similar challenges in managing radioactive waste, e.g. limited infrastructures, financial and human resources, particularly as the small volume makes specialized facilities disproportionately expensive. Equivalently, disposal solutions, generally designed for large waste inventories, are often too costly for countries with small inventories, as the unit cost of disposal becomes very high. Attempts to downscale such concepts have proven ineffective, highlighting the need for dedicated disposal solutions that are safe, practical, and cost-effective for SIMS.

The International Atomic Energy Agency (IAEA) does not provide a strict, formal definition of SIMS; the term is widely used in a descriptive and functional sense. The term is most commonly applied to Member States with Small Quantities Protocols (SPQs) [16]. The Small Quantities Protocol (SQP) is a legal instrument associated with a Comprehensive Safeguards Agreement (CSA) between an IAEA Member State and the Agency. The provisions of the treaty are applicable to states that possess an extremely limited quantity of nuclear material and nuclear activities. Although SQPs are instruments of safeguarding and not waste management tools, they are nevertheless relevant to SIMS as they reflect small-scale nuclear programs, emphasize institutional responsibility and reporting, and often coexist with limited waste management infrastructure.

1.9 Results “Waste Acceptance Criteria – Conditioned Waste”

A representative of COVRA (WMO) has presented the approach of the Netherlands on waste acceptance for interim storage. The waste acceptance procedure and interim storage facilities of the Netherlands are interlinked with the national strategy on waste disposal, where all national radioactive waste will be stored for at least 100 years above ground before final disposal. The focus of the national strategy for the time being lies on isolation, control and monitoring of radioactive waste.

The safety functions for disposal are largely complied with the safety functions for long-term interim storage and are the backbone of the waste acceptance criteria. Nonetheless, specific attention has to be given to the long-lived mobile radionuclides for the disposal. To this aim, COVRA estimates the source term for the different waste families. These are categorised, i. a., by waste origin, conditioning characteristics and waste activity classification.

The waste acceptance procedure at COVRAs facilities relies on four steps, involving both the national waste management organisation COVRA and the waste producer. The process can be simplified into four questions:

- What kind of waste is it? *Information gathering on the waste by the waste producer.*
- What can we do with it? *Determination of waste management routes by the waste management organisation.*
- What targets does it have to meet? *Determination of target values by the waste management organisation, the waste must comply with.*
- How can we do this? *Development of a plan of action by the waste producer to ensure that the waste acceptance criteria are fulfilled.*

When these criteria are complied with, the waste is stored on the COVRA site depending on the waste class LILW (Cat. A to D and NORM) or HLW, and regularly monitored. Disposal concept or combination of them will be decided 2050.

1.10 Impact of Task 5.1 Results

This milestone report shows that managing small amounts of radioactive waste, especially in Small Inventory Member States (SIMS), is a complex, long-term challenge. This cannot be solved by using simplified or scaled-down versions of solutions developed for large nuclear programs. Activities carried out under Task 5.1, including questionnaires, workshops and live discussion forums, have confirmed that effective waste management for small inventories requires a tailored, risk-informed, cooperative approach that integrates technical, regulatory, financial and societal considerations.

The report highlights that no universal or short-term solutions exist across all topics. Legacy and historical waste is often poorly characterized, heterogeneous and undocumented, making careful prioritization and graded approaches essential. Participating in countries' experiences show that combining archival data with modern characterization techniques, supported by robust data management systems, can significantly improve safety, traceability and decision-making. Demonstrated good practices in characterization, conditioning, treatment and interim storage emphasize the importance of clearly defined waste acceptance criteria, standardized packaging concepts and systematic inspection regimes.

The discussions also emphasize that data availability, harmonization and digitalization remain critical enablers. Modern IT tools, non-destructive techniques and data-driven management systems, such as those developed within ICARUS and related EURAD activities, offer significant potential to reduce uncertainty, costs and conservatism, provided they are accessible and adaptable to national needs. Open sharing of methodologies and results at the European level is therefore essential.

For SIMS, the absence of disposal facilities and the disproportionate cost of developing national solutions pose a persistent strategic risk. The report confirms that dedicated disposal concepts, shared infrastructures and EU-supported cooperation mechanisms are indispensable for achieving safe and sustainable waste management. Demonstrator projects are emerging as a key instrument for testing technical solutions, aligning regulatory expectations, building political confidence, and facilitating knowledge transfer.

Finally, the report acknowledges the importance of stakeholder engagement and international cooperation. The early involvement of regulators, policymakers and civil society, alongside structured collaboration between waste managers and research organizations, is vital for building trust and ensuring long-term continuity. This milestone provides a strong foundation for future EURAD-2 activities by consolidating experiences, identifying good practices and clarifying remaining gaps. It also supports the development of pragmatic, harmonized management strategies for small radioactive waste inventories across Europe.

2. PART 2 – ASTRA Task 5.2: Investigation of shared solutions for different radioactive wastes

2.1 Introduction

ASTRA Task 5.2 “Investigation of shared solutions for different radioactive wastes” explores opportunities for sharing predisposal and disposal activities and facilities, including the use of mobile solutions. It also addresses strategic aspects not sufficiently covered in earlier projects, particularly governance, long-term maintenance of specialist expertise, and safety considerations. The work builds on knowledge developed in the EURAD-1 ROUTES Work Package and outcomes from the ERDO Association, while incorporating experience from several European countries representing different stages of RWM programme development.

The information provided in this report is based on a questionnaire complemented by three workshops. The first workshop focused on presenting and discussing the questionnaire results in detail, while the second workshop reviewed potential technical solutions available on the market and outcomes from parallel projects. The third workshop aimed to address knowledge gaps identified in the ASTRA Green Paper [17] and to consolidate final insights. All Task 5.2 activities together allowed a systematic collection and analysis of data on shared solutions for predisposal and disposal of radioactive waste, considering technical, societal, and governance aspects.

Section 2.2 of this report presents the methodology applied in ASTRA Task 5.2 for investigating shared solutions for radioactive waste management. The subsequent sections present the results of the questionnaire and workshops, general collective information on participants (excluding specific information), radioactive waste inventory and management needs, national policies on import and export, as well as factors affecting shared solutions, including governance, benefits, and opportunities. The chapter concludes with a summary and outlook, providing recommendations for optimising shared solutions and identifying areas for further research and collaboration.

2.2 Methodology

ASTRA Task 5 subtask “Investigation of shared solutions for different radioactive wastes” (ASTRA Task 5.2) investigates the potential for sharing of (pre)disposal activities and facilities, including the possible mobile solution. The main basis of Task 5.2 were EURAD-1 ROUTES reports on shared solutions and outcomes from ERDO Association work, i.e., deliverables D9.12 [18] and D9.13 [19]. The focus of Task 5.2 lay on strategic issues not addressed in previous projects: governance, maintenance of specialist competencies, and safety on a longer-term basis.

The Task 5.2 methodology was designed to gather, analyse, and integrate existing knowledge and practical experience of shared radioactive waste management solutions, while identifying gaps and potential opportunities. Information was collected through a four-step approach involving a questionnaire and three online workshops with task participants, end users and stakeholders.

Questionnaire. As a starting point, a questionnaire (Appendix B) was circulated among the participating organisations, as well as end-users and stakeholders involved in ASTRA Task 5, to collect information on the current status, practices, and challenges related to shared solutions. The questionnaire covered strategic, technical, and regulatory aspects, providing a comprehensive baseline for further discussions.

The questionnaire consisted of two main parts. The first part of the survey collected general information on the respondents, including their country, organisation and EURAD college (Waste Management Organisation (WMO), Technical Safety Organisation (TSO), Research Entity (RE), Civil Society (CS), or other), as well as their contact details. The second part addressed more specific topics, including involvement in the EURAD-1 ROUTES and EURAD-2 ASTRA, the types and management requirements of radioactive waste (main sources, disposal strategies, and deep geological repository requirements), national policies and strategies for import and export of radioactive waste, and potential benefits, opportunities, governance, and other factors affecting shared solutions. In total, the questionnaire included 26 questions.

Workshops. In the first workshop, the initial results of the questionnaire were presented in detail and discussed among the participants. This allowed for verification of the collected data, clarification of any inconsistencies, and identification of specific challenges requiring further attention.

The second workshop focused on showcasing a potential solution available on the market, as well as outcomes and relevant experiences from parallel projects. This session aimed to integrate external knowledge and state-of-the-art practices into the discussion, enabling a more comprehensive assessment of feasible shared solutions.

The third workshop addressed knowledge gaps identified in the Green Paper and in previous discussions. Participants provided additional information and perspectives, contributing to the final refinement of recommendations and strategies for shared solutions in radioactive waste management.

2.3 Results of the Questionnaire – Overview

The ASTRA Task 5.2 questionnaire was circulated among Task 5 participants, interested end-users, and stakeholders in order to establish a structured overview of national contexts and perspectives on shared solutions for radioactive waste management. In total, 24 responses were received covering 17 countries. The geographical distribution of responses was as follows:

- One reply per country: Bulgaria, Czech Republic, Estonia, Finland, Germany, Greece, Italy, Poland, Portugal, Switzerland, USA.
- Two replies per country: Austria, Denmark, Netherlands, Slovenia, Ukraine.
- Three replies per country: France.

This distribution reflects participation from both single-organisation national programmes and countries where multiple institutions contributed separately, thereby providing a broader internal perspective on shared solutions within those national contexts. The respondents represented five categories of actors: Research Entities (RE), Waste Management Organisations (WMO), Technical Safety Organisations (TSO), Civil Society (CS), and Industry (Figure 2). This ensured that operational, regulatory, research, industrial, and societal viewpoints were included in the evaluation. It should be emphasised that the responses are not statistically representative and only reflect the views of the participating partners.

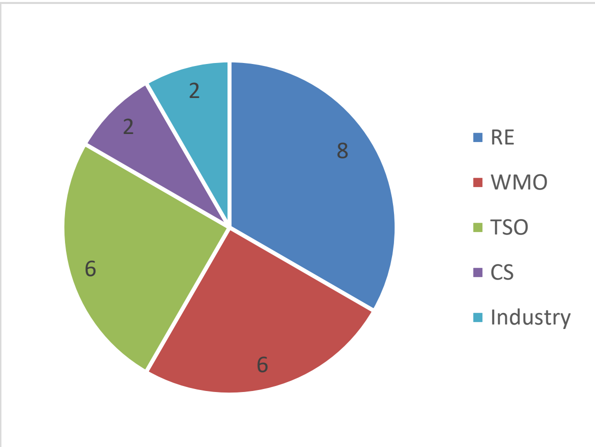

Figure 2 - Participants in the survey by actor type (with numbers of responds)

Overall, the results confirm that the questionnaire responses were obtained from a diverse and competent stakeholder group with direct involvement in radioactive waste management, safety assessment, research, policy advisory functions, and societal engagement. This provides a robust and representative basis for analysing the more detailed technical and governance-related aspects.

Regarding involvement in EURAD activities, a significant proportion of respondents indicated participation in EURAD-2 ASTRA, including Task 5. In addition, several organisations confirmed prior involvement in EURAD-1 ROUTES, including familiarity with ROUTES Task 6 on shared solutions. This demonstrates that the survey captured both organisations with previous experience in shared solution discussions and those engaging with the topic for the first time.

Also, according to the survey results, the majority of responding countries (> 80 %) generate RW and/or SNF that requires a deep geological repository (DGR), confirming that DGR implementation represents a common long-term management need across Europe and reinforcing the relevance of exploring shared or multinational disposal solutions.

2.4 Results on “National Policy and Legal Framework”

Regarding national policies on adopting a dual-track approach (pursuing national and multinational shared solutions in parallel) 50 % of the respondents indicated that such an approach is not under consideration in their country (Figure 3). However, 37.5 % reported that this model is already incorporated into their strategic framework. The remaining 12.5 % were uncertain whether a dual-track approach forms part of their national policy.

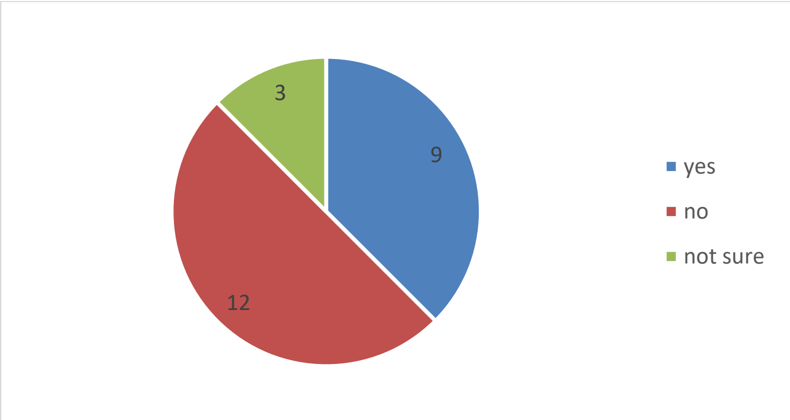

Figure 3 - Consideration of a dual-track approach by participants

Several countries are considering a dual-track approach for the management of radioactive waste and spent fuel to maintain strategic flexibility under conditions of long implementation timelines, technical uncertainty, and political risk. Among countries pursuing such a strategy (5 countries with 9 replies), 80 % express interest in shared geological disposal, 65 % in sharing predisposal services, 65 % in collaboration for training, and 45 % in shared near-surface disposal. Geological disposal programmes require decades of site characterisation, licensing, and societal consent; maintaining both national and potential multinational options mitigates the risk of programme delay or failure. For smaller inventories in particular, shared solutions may offer economies of scale and proportional cost efficiency, while national pathways safeguard the principle of ultimate state responsibility and regulatory control. A dual-track strategy therefore functions as a risk-management instrument, balancing sovereignty, feasibility, cost optimisation, and long-term safety assurance.

This demonstrates that commitment to shared geological solutions is markedly stronger among dual-track countries. The dual-track strategy therefore operates as a structured risk-management instrument given the multi-decadal timelines, technical complexity, financing demands, and societal challenges of geological disposal programmes, maintaining both national and multinational pathways preserves strategic flexibility. Shared solutions may offer economies of scale, particularly for smaller inventories, while continued development of national options safeguards regulatory sovereignty and ultimate state responsibility.

Legal framework for import or export legal ban for RW and SNF also provides differences among participants. Based on the reported results, 50 % of respondents indicate that national legislation prohibits the import of RW or SF, whereas 33 % report a legal ban on export. Conversely, 29 % state that import is not prohibited and 50 % report that export is permitted. A non-negligible proportion of respondents, 21 % import and 17 % for export, were uncertain about the legal status in their country. The results from questionnaire are given in Table 1.

Table 1: Results for legal ban on import or exports for RW or SF by participants

	BAN ON IMPORT	BAN OF EXPORT
YES	12	8
NO	7	12
NOT SURE	5	4

The results reveal two notable governance issues. First, import restrictions appear more prevalent than export restrictions, suggesting a stronger national sensitivity to accepting foreign waste than to transferring domestic waste abroad. Second, inconsistencies were observed among respondents from the same country (different responds about ban for the same country), indicating either differences in interpretation (e.g., distinction between interim storage and disposal) or limited awareness of the precise legal framework.

Moreover, comparison with official national submissions (e.g., [20]) identified discrepancies in approximately 20 % of cases, highlighting potential gaps between perceived and formally established regulatory positions. These findings underscore that legislative clarity, regulatory harmonisation, and transparent communication are critical preconditions for advancing shared or multinational disposal solutions.

2.5 Results on "Drivers and Areas of Cooperation"

In response to the question about the existing collaboration between organisations for sharing of RWM activities and facilities, the majority of respondents indicated that no such collaboration is currently in place (Figure 4). Specifically, 62.5 % reported that there is no existing collaboration, while 29.2 % confirmed that they are already engaged in cooperative arrangements. A small proportion of respondents (approximately 4 – 5 %) were unsure or question was not applicable for their organisation.

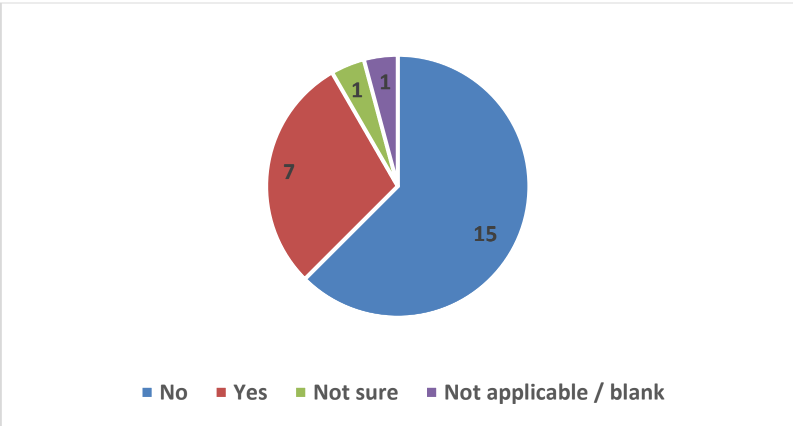

Figure 4 - Existing collaboration between organisations for sharing of RWM activities and facilities

These results suggest that, although more than one third of organisations are already participating in shared RWM activities or facilities, formalised collaboration is not yet the prevailing model. The relatively high proportion of negative responses indicates significant unexploited potential for expanding cooperative frameworks in radioactive waste management.

The cooperation is mainly driven by practical needs rather than abstract strategic considerations. Based on 24 replies from five different actors (Table 2), the results clearly indicate that technical, financial and safety-related aspects are the dominant drivers for collaboration. Technical drivers are particularly strong among TSOs and Research Entities and are also highly relevant for WMOs and Industry. Financial considerations are equally important, especially for WMOs and Research Entities, and remain significant for TSOs and Industry. Safety and security concerns play a major role across most actor groups and are particularly emphasised by Research Entities, WMOs and Industry. Societal drivers are relevant but less dominant overall. In contrast, safeguards and liability issues appear to play only a minor role in motivating collaboration.

Table 2: Main drivers for collaboration by actor group (number of responses)

Driver for collaboration	RE (n=8)	WMO (n=6)	TSO (n=6)	CS (n=2)	Industry (n=2)
Technical	6	4	5	1	2
Financial	6	5	3	1	2
Safety and security	7	5	4	1	2
Societal	4	3	3	1	1
Safeguards	1	1	1	0	0
Liabilities	1	1	1	0	0

Knowledge sharing and training clearly emerge as the most common areas of interest across all colleges. Around 90 % of respondents identify knowledge exchange and training as key cooperation areas, and approximately 73 % emphasise the importance of maintaining specialist competences over the long term. Pooling resources for joint tenders and early-stage generic studies is also important (around 60 %). Around 40 % indicate interest in shared disposal facilities. Of these respondents 87 % were interested in cooperation on shared geological disposal, 67 % were interested in shared near surface disposal and 44 % were interested in both shared options (near surface and deep geological facilities).

Interest in mobile solutions varies around 50 % overall. Where mobile solutions are supported, they are mainly linked to characterisation, treatment and packaging technologies. This indicates that mobile systems are primarily seen as tools for waste characterisation and predisposal support rather than as central disposal solutions. Interest is somewhat higher among organisations already involved in EURAD ROUTES (around 75 %), where characterisation, treatment and packaging are again the main focus.

Regarding specific collaboration types, recycling and reuse of materials receive relatively strong support, particularly among WMOs and REs. However, take-back options including spent fuel show very limited interest overall. This suggests that such options are either politically sensitive, strategically uncertain or relevant only to specific waste owners.

A common and important area across all colleges is collaboration on safety case development. Although the depth of cooperation is not specified, many respondents express interest in joint work on generic safety cases, harmonisation of methodologies and refinement of costing approaches. Safety case-related cooperation therefore stands out as one of the most strategically attractive and widely supported activities.

2.6 Results on "Areas and Drivers for Cooperation in Countries Interested in SMR/AR"

Regarding plans for introducing Small Modular Reactors (SMR) and Advanced Reactors (AR) in counties, 15 respondents (63 %) indicate that there are plans for introducing SMR and/or AR in their country, 6 respondents (25 %) report no such plans, and 3 respondents (12 %) are uncertain (Figure 5).

Countries confirming plans reflect varying degrees of maturity. Estonia formally endorsed nuclear energy preparation in 2024 and is considering deployment of the BWRX-300 SMR. France is advancing a broad portfolio of SMR/AR technologies, including micro-reactors, PWR-based SMRs (NUWARD), lead- and sodium-cooled fast reactors, molten salt reactors, and district-heating applications. Ukraine is negotiating deployment of several SMR designs (AP300, SMR-300, NUWARD). The Czech Republic is progressing light-water SMR development through multiple national and international research projects. The Netherlands has announced exploration of SMR deployment alongside large reactors, particularly for electricity and industrial heat. Slovenia foresees SMRs in its National Energy and Climate Plan (post-2050), and discussions have also begun in Greece, including applications for electricity generation and AI/data centre power supply. The USA and other respondents confirm evolving SMR/AR programmes.

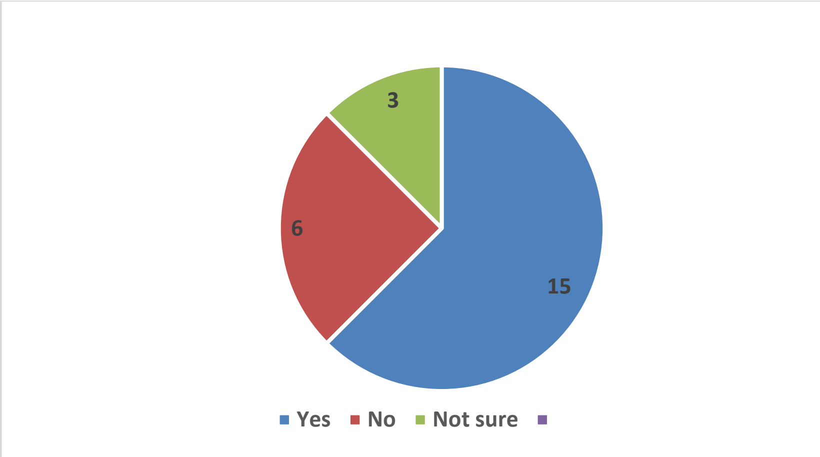

Figure 5 – Plans for introducing Small Modular Reactors and Advanced Reactors in counties

Where respondents commented on mobile solutions (linked to a "Yes" answer), the emphasis is predominantly on treatment and conditioning of radioactive waste and interim spent fuel storage, rather than on mobile reactors themselves. Some responses highlight the need for alternative treatment and conditioning approaches to address novel waste streams (e.g. lead-, sodium-, or alpha-bearing waste from advanced reactor concepts). This suggests that mobile solutions are primarily viewed as supportive infrastructure for waste management in the context of diversified SMR deployment.

For question that, with multiple SMRs widely spread in locations over the EU, would give more potential and need for regional and shared RW management solutions, 13 respondents (54 %) agree, 4 respondents (17 %) disagree, generally emphasising national responsibility and legal constraints, while 6 respondents (25 %) are uncertain, often due to legislative or governance considerations. One response (4 %) did not provide a clear position. Arguments in favour focus on economies of scale, efficiency gains, avoidance of infrastructure duplication, particularly in smaller or newcomer states and enhanced safety, harmonisation, and proliferation control. Dissenting views stress that each country must develop adequate national waste management structures regardless of SMR deployment.

With respect to Q22 (Appendix B), organisational interest is concentrated primarily on predisposal and circular economy options rather than shared final disposal infrastructure. The most frequently selected option is sharing reuse of materials (12 respondents, 50 %), followed by recycling (10 respondents, 42 %). Decontamination services and returning sources to suppliers are each selected by 8 respondents (33 %), while reprocessing is chosen by 7 respondents (29 %). Take-back options including spent fuel are indicated by 3 respondents (13 %), and only 1 respondent (4 %) explicitly expresses interest in geological disposal facility development.

2.7 Results on "Governance of joined DGR activities"

The responses to the interest in the joint development of generic designs for Deep Geological Repositories (DGRs) show a clear majority interest in joint technical approach. 14 out of 24 organisations (58 %) state that they would be interested in the joint development of generic DGR designs, preparation of generic safety cases, and/or harmonisation and refinement of costing methodologies, while 9 organisations (38 %) respond negatively and 1 (4 %) remains undecided. Among those supporting joint development, the strongest emphasis is placed on generic safety case preparation and safety assessment methodologies, including long-term and post-closure safety demonstration. Several respondents also highlight the importance of harmonising costing approaches, siting procedures, and regulatory assessment frameworks. Smaller or newcomer countries particularly underline the benefit of avoiding duplication of effort and "reinventing the wheel", noting that generic concepts could strengthen national programmes through shared knowledge, resource pooling, and methodological consistency.

For question whether Deep Borehole Disposal (DBD) can be one of future shared options, an even stronger level of alignment is observed. 17 out of 24 respondents (71 %) recognise DBD as a potential future shared disposal option, whereas 5 respondents (21 %) do not currently consider it viable and 2 (8 %) are undecided. The inventories identified as potentially suitable for DBD include spent nuclear fuel (SNF), high-level waste (HLW), vitrified residues from reprocessing, long-lived intermediate-level waste (ILW), high-activity sealed sources (HASS), research reactor fuel, and specific national inventories such as VVER and RBMK SNF. At the same time, several respondents caution that DBD requires further development, particularly regarding operational feasibility, long-term safety case demonstration, and regulatory maturity before being established as a fully credible alternative to mined geological repositories.

Regarding willingness to collaborate in stakeholder engagement with consent-based siting for shared solutions, 12 out of 24 organisations (50 %) state that they would be willing to collaborate in developing or progressing stakeholder engagement, while 11 organisations (46 %) respond "No" and 1 (4 %) remains undecided. Those willing to collaborate emphasise that shared solutions require an even stronger governance framework than national programmes. Key proposals include early and continuous stakeholder engagement from the conceptual phase onwards, transparent and stepwise decision-making processes, transboundary participation mechanisms (in line with Aarhus and Espoo principles), and clear identification of beneficiaries and host communities. Several respondents stress the need for a "level playing field" among participating countries to avoid environmental or social dumping, as well as fair benefit-sharing mechanisms and voluntary municipal participation. Even among organisations answering "No", many underline that robust safety culture, harmonised regulatory standards, and inclusive governance are prerequisites for legitimacy.

For the most important issues which needs to be addressed, governance and societal issues are widely recognised as critical components of any shared disposal solution. The most frequently selected issues concern: who should be involved in the site selection process, what minimal standards for site selection should apply, what safety and security requirements should govern the facility, who should be included in the decision-making process, and how to ensure effective public participation. Numerous respondents indicate that all listed governance elements are important. Comments repeatedly highlight the need for harmonised safety and security standards across participating countries, clearly defined roles and responsibilities, an agreed legal framework, and sufficient financial and human resources. Public participation and transparency are viewed as essential for building trust, particularly in a cross-border context. Several responses emphasise that decision-making timelines should be linked to technical progress rather than political pressure, and that stakeholder engagement must continue throughout the entire lifecycle of the facility—from siting to closure and institutional control.

2.8 Summary & Outlook

The results of ASTRA Task 5.2 confirm that shared solutions in radioactive waste management are a strategically relevant option for a substantial proportion of European programmes. More than 80 % of responding countries generate radioactive waste and/or spent fuel requiring DGR, underlining the common long-term need across Europe. At the same time, only around 30 % of organisations report existing formalised collaboration for sharing facilities or activities, indicating significant untapped cooperation potential.

Collaboration is primarily driven by technical, financial, and safety considerations. Knowledge exchange and training are identified as key cooperation areas by approximately 90 % of respondents, followed by maintenance of specialist competences (≈ 73 %) and pooling resources for early-stage generic studies (≈ 60 %). Interest in shared disposal facilities is expressed by 41 % of respondents, with stronger support for shared geological disposal than for near-surface options. These findings demonstrate that cooperation is currently perceived as most beneficial in preparatory and technical domains rather than in immediate infrastructure sharing.

Regarding joint development of geological disposal concepts, 58 % of organisations express interest in contributing to generic DGR designs, safety case development, and harmonised costing methodologies. Generic safety case preparation and post-closure safety assessment emerge as priority areas. This reflects broad recognition that harmonisation can reduce duplication of effort, support smaller or newcomer programmes, and strengthen regulatory confidence.

DBD receives even stronger support: 71 % of respondents recognise it as a potential future shared disposal option. Inventories considered potentially suitable include spent nuclear fuel, vitrified high-level waste, long-lived intermediate-level waste, sealed sources, and research reactor fuel. However, several respondents emphasise that DBD requires further technical maturation, operational demonstration, and robust long-term safety case development before it can be regarded as a fully credible alternative to mined repositories.

Governance and societal aspects are identified as decisive enabling factors. Half of the organisations (50 %) indicate willingness to collaborate in developing consent-based siting approaches for shared solutions. Responses consistently highlight the need for early and continuous stakeholder engagement, transparent and stepwise decision-making, harmonised safety and security standards, and clearly defined roles and liabilities. Transboundary participation mechanisms, consistent with Aarhus and Espoo principles, are considered essential for multinational solutions. Even organisations not actively supporting CBS development recognise that strong governance frameworks are a prerequisite for legitimacy.

National policy frameworks remain heterogeneous. Approximately 38 % of respondents report that their country considers a dual-track strategy (national and multinational pathways in parallel), indicating that shared solutions are increasingly viewed as a risk-management instrument rather than a fallback option. At the same time, 50 % report legal bans on import of radioactive waste, while export restrictions are less common, demonstrating regulatory complexity that must be addressed before multinational implementation can advance.

The emergence of Small Modular Reactor and Advanced Reactor programmes in over 60 % of responding countries adds a forward-looking dimension. More than half of respondents agree that widespread SMR deployment could increase the need for regional or shared waste management solutions, particularly to avoid infrastructure duplication and ensure economies of scale.

Overall, Task 5.2 delivers three key impacts:

- A structured and quantified overview of European stakeholder positions on shared solutions.
- Identification of priority cooperation areas, notably safety case harmonisation, costing methodologies, knowledge exchange, and predisposal collaboration.
- Clarification that governance, legal alignment, and societal engagement are as critical as technical feasibility.

3. List of Figures

4. List of Tables

5. References

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Appendix A: ASTRA Task 5.1 Questionnaire

EURAD-2: WP3 ASTRA Sub-Task 5.1

Analysis of management strategies for small amounts of waste

Development of the contextual topics for exchange in the Community of Practice

DMT – Dr M. C. Bornhöft

Survey and background (ROUTES outputs) were presented at the ASTRA Task 5 Kick-off meeting by Dr M. C. Bornhöft.

The presentation can be found in the ASTRA Project place.

The aim of this survey is to identify topics for further discussion based on interest from community of practice participants. The results of this survey will be used to rank and subsequently select waste management steps, waste streams and waste categories of most significance. Within the community of practice platform, the highest-ranked topics will be discussed over the duration of ASTRA WP.

The selection of waste streams, waste categories and waste management steps covered by the survey have been identified within the first EURAD project from 2019 to 2024. In tangible terms, the survey covers the fusion of open topics from EURAD ROUTES Deliverable 9.3 (*Recommendations for R&D, strategic study and KM activities for future European collaboration*) and EURAD ROUTES Deliverable 9.22 (*Summary report on analysis, assessment and evaluation of disposal options for SIMS*), as well as the "challenging waste types" from EURAD ROUTES Deliverable D9.5 (*Overview of issues related to challenging waste*).

For this survey, we ask you to fill in a pre-populated, multiple-choice answer questionnaire regarding the predisposal and disposal of different waste types and waste categories. Please select the waste type/category that is of greatest concern/importance to your organisation or provide further details if it is not found within the pre-populated list (use the option "other"). Questions with * are mandatory.

General Information Questions	
Q1	**Country** *Please provide the name of your country and classify according to SIMS/LIMS and LAP/MAP*
	Click here to enter text.
	☐ Small Inventory Member State (SIMS) ☐ Large Inventory Member State (LIMS)
	☐ Less advanced program on radioactive waste management (LAP) ☐ More advanced program on radioactive waste management (MAP)
Q2	**Organisation** *What is the name of your organisation or institute, and what is your organisation's role in the management of radioactive waste in your country?*
	Organisation / Institute: Click here to enter text. **Role:** Click here to enter text.
Q3	**Contact Information** *Please provide the name, email address, and position of the contact person responsible for this survey.*

	Name: Click here to enter text. **E-mail address:** Click here to enter text. **Position:** Click here to enter text.
Topics of Interest	
Q4	**Initial Waste Inventory** *Regarding the waste inventory, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	Waste Types: ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. Waste Categories: ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q5	**Predisposal step: Characterization** *Regarding the predisposal step of characterization, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	Waste Types: ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite

	☐ Other (Please specify) Click here to enter text. <u>Waste Categories:</u> ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q6	**Predisposal step: Treatment** *Regarding the predisposal step of treatment, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	<u>Waste Types:</u> ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. <u>Waste Categories:</u> ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q7	**Predisposal step: Conditioning** *Regarding the predisposal step of conditioning, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	<u>Waste Types:</u> ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources

	☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. <u>Waste Categories:</u> ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q8	**Interim Storage Solutions** *Regarding the topic of interim storage, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	<u>Waste Types:</u> ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. <u>Waste Categories:</u> ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q9	**Development of Waste Acceptance Criteria** *Regarding the topic "development of waste acceptance criteria", what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	<u>Waste Types:</u> ☐ Sludge ☐ Organics

	☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. Waste Categories: ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Q10	**Scalable Disposal Solutions** *Regarding the topic of scalable disposal solutions, what types of waste are of interest to your organisation to discuss on the community of practice platform?*
	Waste Types: ☐ Sludge ☐ Organics ☐ Concrete ☐ Metals ☐ Disused sealed radioactive sources ☐ Spent ion exchange resins ☐ U/Ra/Th bearing wastes ☐ Graphite ☐ Other (Please specify) Click here to enter text. Waste Categories: ☐ Conditioned wastes (e.g. cemented, bitumized, etc) ☐ Legacy wastes (please state your country's definition of legacy waste: Click here to enter text.) ☐ Hazardous waste (e.g. asbestos, etc.) ☐ Other (Please specify) Click here to enter text.
Civil Society Aspects	
Q11	**Policy**

	Does your country have or plans to have a transparency policy on the radioactive wastes?
	Please specify the extent and limitation of public transparency. Click here to enter text.
Q12	**Present Public Participation** *Are you aware of public participation on radioactive wastes in your country?*
	Please specify the extent and limitation of public participation. Click here to enter text.
Q13	**Future Public Participation** *Is your organisation involved or plans to be involved in public participation on radioactive wastes?*
	Please describe Click here to enter text.
Additional Information	
Q14	**Future Projects** *Are there any other issues you would like to see discussed on the community of practice platform? Please briefly describe them.*
	Click here to enter text.
Q15	**Other Comments**
	Click here to enter text.

Appendix B: ASTRA Task 5.2 Questionnaire

EURAD-2: WP3 ASTRA Sub-Task 5.2

Investigation of shared solutions for different RW

A protocol for a survey on shared solutions and the potential for sharing of predisposal & disposal activities and facilities

ARAO – L. Kegel

The survey was presented at the Task 5.1 meeting by L. Kegel.
The presentation can be found in the **ASTRA Project place**.

This questionnaire has been developed by a sub-task group of the EURAD-2 Work Package 3 – ASTRA. Task 5, within ASTRA, aims to analyse management strategies for diverse and challenging wastes by supporting exchanges of experiences and best practices in the forum for community of practice between Large Inventory Member States (LIMS) and Small Inventory Member States (SIMS). To elaborate disposal strategies and waste management solutions for specific challenging wastes that do not meet existing Waste Acceptance Criteria (WAC) and investigate shared solutions for different radioactive wastes: sharing of predisposal & disposal activities and facilities, strategic issues not addressed in previous projects.

This work builds on EURAD-1 ROUTES reports on shared solutions and outcomes from ERDO Association work further investigating the potential for sharing of predisposal & disposal activities and facilities, including the possible mobile solutions. The questionnaire consists of two parts. The first shorter part consists of general questions about respondent, and the second part consisting specific questions about EURAD 1 Routes WP involvement that are followed by questions on RW inventory and its management needs and requirements, national policy and strategy for import and export of RW and about drivers, benefits, opportunities, governance and other factors impacting shared solutions.

In this survey, questions with * are mandatory.

In a case where there is a need to fill in the survey in a Word file, please send the filled form located in the ASTRA ProjectPlace to leon.kegel@arao.si.

General Information Questions	
Q1	**Country** *Please provide the name of your country.*
	Click here to enter text.
Q2	**Organisation** *What is the name of your organisation or institute, and what type of actor it is?*
	Organisation / Institute: Click here to enter text. **Type of actor:** ☐ Waste Management Organisation (WMO) ☐ Technical Safety Organisation (TSO) ☐ Research Entity (RE) ☐ Civil Society (CS)

	☐ Other (Please specify) Click here to enter text.
Q3	**Contact Information** *Please provide the name, email address, and position of the contact person responsible for this survey.*
	Name: Click here to enter text. **E-mail address:** Click here to enter text. **Role in the organisation:** Click here to enter text.
Questions for the development of the survey on Shared Solutions	
Q4	**Your involvement in EURAD-2 WP3 ASTRA** *Select all that apply.*
	☐ T1 Management / Coordination of the WP ☐ T2 Knowledge Management ☐ T3 RW long-term storage ☐ T4 Deep borehole disposal ☐ T5 Alternative waste management solutions for SIMS ☐ T6 Interaction with Civil Society
Q5	**Your involvement in WP3 ASTRA TASK 5** *Select all that apply.*
	☐ Subtask 5.1 Analysis of management strategies for a small amount of waste ☐ Subtask 5.2 Investigation of shared solutions for different RW ☐ Subtask 5.3 Evaluation of RWM strategies for the disposal of waste bearing naturally occurring long-lived radionuclides
Q6	**Your involvement in EURAD 1 ROUTES project** *Please select.*
	☐ Yes ☐ No
	If the answer is YES, have you/your organisation been involved in ROUTES Task 6: Shared solutions in European countries?
	☐ Yes ☐ No
	Are you familiar with the ROUTES Task 6 results and recommendations for further work?
	☐ Yes ☐ No

	☐ Other (Please specify) Click here to enter text.
Q7	**What types of radioactive waste (RW) and Spent Fuel (SF) are generated in your country?** *Select all that apply.*
	☐ Very low-level waste (VLLW) ☐ Low-level waste (LLW) ☐ Intermediate level waste (ILW) ☐ Low and Intermediate level waste (LILW) ☐ High level waste (HLW) ☐ SF from nuclear power reactors (NPP) ☐ SF from Research Reactors (RR) ☐ Naturally occurring radioactive material (NORM) and Technologically enhanced naturally occurring radioactive material (TE(NORM)) if classified as RW ☐ Other RW categories according to national classification (Please specify) Click here to enter text. ☐ Not sure
Q8	**What are the main sources of radioactive waste?** *Describe where RW is generated (max 4 lines).*
	Click here to enter text.
Q9	**What is main RW disposal strategy in your country?** *Please describe (max 4 lines).*
	Click here to enter text.
Q10	**Is RW or SF generated in your country that requires deep geological disposal?** *Please select.*
	☐ Yes ☐ No ☐ Other (Please specify) Click here to enter text. ☐ Not sure
	If the answer is YES, what type of RW or SF? (max 4 lines)
	Click here to enter text.
Q11	**Is there a legal ban for the import of RW or SF in your country?** *Please select.*
	☐ Yes

	☐ No ☐ Not sure
	If the answer is YES/NO, please elaborate. (max 4 lines)
	Click here to enter text.
Q12	**Is there a legal ban for export of RW or SF in your country?** *Please select.*
	☐ Yes ☐ No ☐ Not sure
	If the answer is YES/NO, please elaborate. (max 4 lines)
	Click here to enter text.
Q13	**Does your country's policy consider a dual-track approach (national & multi-national shared solutions in parallel)?** *Please select.*
	☐ Yes ☐ No ☐ Not sure
	If the answer is YES/NO, please elaborate. (max 4 lines)
	Click here to enter text.
Q14	**Is there an existing collaboration between your and another organisation for sharing RW management activities and facilities?** *Please select.*
	☐ Yes ☐ No ☐ Not sure
	If the answer is YES, what is the type of cooperation? Please describe. (max 5 lines)
	Click here to enter text.
Q15	**In what areas do you see most opportunities for cooperation and sharing?** *Please indicate the most important ones. (max is 4)*
	☐ Collaboration for training, exchange of knowledge and practice, documentation, … ☐ Maintenance of specialist competencies on longer scales

	☐ Pooling together resources for implementing joint tenders and projects in early and planning stage (generic studies) ☐ Sharing predisposal activities/services (treatment, conditioning, …) ☐ Sharing predisposal facilities ☐ Shared storage ☐ Shared geological disposal ☐ Shared disposal of RW that does not require geological disposal ☐ Other (Please specify) Click here to enter text.
	Please comment your selection. (max 5 lines)
	Click here to enter text.
Q16	**Which of the above listed opportunities would be most beneficial for your organisation and why?** *Please describe. (max 6 lines)*
	Click here to enter text.
Q17	**What are the drivers for such collaboration?** *Please indicate the most important ones. (max is 3).*
	☐ Financial ☐ Technical (geology, design considerations, specific waste streams, conditioning issues, …) ☐ Societal ☐ Safety and Security ☐ Safeguards ☐ Liabilities ☐ Other (Please specify) Click here to enter text.
	Please comment your selection. (max 5 lines)
	Click here to enter text.
Q18	**Is your organisation interested in sharing mobile solutions for predisposal and disposal activities?** *Please select.*
	☐ Yes ☐ No
	If the answer is YES, please comment which mobile solution would benefit most for you. (max 5 lines)
	Click here to enter text.

Q19	**What are main reasons for your organisation as a potential customer/collaborator to be interested in collaborating in shared disposal?** *Please indicate the most important ones. (max is 3).*
	☐ Economics and financial arrangements ☐ Technical requirements ☐ Legal, institutional and regulatory requirements ☐ Security and environmental safety requirements (Non Proliferation and Physical Protection) ☐ Environmental issues ☐ Sharing future liabilities and responsibilities ☐ Other (Please specify) Click here to enter text.
	Please comment your selection. (max 5 lines)
	Click here to enter text.
Q20	**Are there plans for introducing Small Modular Reactors (SMRs) and Advanced Reactors (ARs) in your country with a variety of their future use (electricity production, hydrogen production, district heating, desalinization, powering data and Artificial Intelligence (AI) centres, ….)?** *Please select.*
	☐ Yes ☐ No ☐ Not sure
	If the answer is YES, please comment. (max 5 lines)
	Click here to enter text.
Q21	**Do you agree that with multiple SMRs widely spread in locations over the EU would give more potential and need for regional and shared RW management solutions?** *Please select.*
	☐ Yes ☐ No ☐ Not sure
	Why? Please comment. (max 5 lines)
	Click here to enter text.
Q22	**Which option is your organisation interested in?** *Please choose all that apply.*

	☐ Sharing reuse of materials ☐ Decontamination services ☐ Recycling ☐ Reprocessing ☐ Returning sources to suppliers ☐ Take back options including SF ☐ Other (Please specify) Click here to enter text.
	Please comment your choice. (max 5 lines)
	Click here to enter text.
Q23	**Would your organisation be interested in the joint development of generic designs for Deep Geological Repositories (DGRs), preparing generic safety case, harmonizing and refining costing methodology/ies, …?** *Please select.*
	☐ Yes ☐ No
	If your answer is YES, please comment which activity could be in most interest to you. (max 5 lines)
	Click here to enter text.
Q24	**Do you recognize Deep Borehole Disposal (DBD) as one of future shared disposal options?** *Please select.*
	☐ Yes ☐ No
	If your answer is YES, please comment on what kind of RW and SF inventory would be in your interest to be disposed in deep boreholes. (max 5 lines)
	Click here to enter text.
Q25	**Would your organisation be willing to collaborate in developing/progressing stakeholder engagement with consent-based siting for shared solutions?** *Please select.*
	☐ Yes ☐ No
	If your answer is YES, please provide some ideas on how consent-based siting for shared solutions could be complemented in comparison to the siting of facilities in national programmes. (max 5-6 lines)

	Click here to enter text.
Q26	**Governance and societal issues of shared solution for RW disposal should be addressed. What are the most important issues which needs to be addressed?** *Please select. (max is 4)*
	☐ How to start the site selection process? ☐ Who should be involved in the site selection process? ☐ Who should be included in designing the site selection process? ☐ What would be the minimal standards for site selection? ☐ What safety and security requirements should apply? ☐ What conditions should be offered to the host community? ☐ Who would be included in decision making process? ☐ How long decision making should take place? ☐ How to ensure public participation in the site selection process? ☐ Other (Please specify) Click here to enter text.
	Please comment your selection. (max 5 lines)
	Click here to enter text.
Q27	**Do you have any other comments or suggestions?**
	Click here to enter text.