# Deliverable 9.14: The feasibility of developing further European shared solutions for waste management from cradle to grave

Work Package 9

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# Executive Summary

The exploration of shared waste management solutions within ROUTES, and more specifically in Task 6, provided a comprehensive assessment of the feasibility of developing further European shared solutions for waste management from cradle to grave, on the basis of the collective experience and lessons learned by member states. Considering insight from ROUTES and ERDO, this report identifies promising topics and waste streams that could lead to opportunities for collaborative solutions between member states.

Several challenging waste streams have been identified, including sludges, graphite, particular spent fuel, disused sealed radioactive sources, reactive metals, chemotoxic substances, spent radioactive ion-exchange resins and organic waste (both solid and liquid). The challenges associated with these waste streams often lies on the lack of comprehensive characterization, treatment, and disposal routes. The relatively small volumes linked to these waste streams make them suitable for shared solutions.

A particular interest emerged in the potential sharing of mobile treatment and characterization facilities, particularly for addressing challenges related to the characterization and treatment of sludges and resins. Representative sampling was also identified as a significant obstacle for successful waste characterization. Small inventory member states (SIMS) indicated resource constraints, notably to implement the characterization of their radioactive waste for decommissioning, due to the need for heavy infrastructures and specific skills. Consequently, the possibility of setting up an R&D programme on radiological characterization equipment that can be shared and transported between countries was discussed. This leads to the recommendation to develop a mobile facility for radioactive waste characterization, treatment or conditioning (ROUTES recommendation R&D-1).

Even though several topics of common interest and suitable for shared solutions were identified, practical bottlenecks were also recognized: standard procedures, common waste classification, common understanding to WACs and harmonized regulations, were highlighted as topics which needed further development to achieve effective shared solutions. It is notably evident that sharing predisposal and disposal facilities needs important work in regulatory and Waste Management (WM) procedures harmonization. While technical research is needed, the advancement of shared solutions relies heavily on political decisions.

In this societal-political context, it is important to keep in mind civil society (CS) Task input to achieve a level playing field for the collaborators and lessons learned from case studies showing the importance of public consultation. This consideration leads to the recommendation to "harmonize procedures to facilitate collaboration between member states" (ROUTES recommendation StSt-3), aiming at clarifying the complexities associated with determining the necessary procedures and permits, which can be both time-consuming and resource-intensive. Simplifying this process requires harmonizing the various steps needed to enhance the possibility of operating commercial treatment facilities outside national borders, help reducing storage periods and improve safety of workers, environment, and population, and encourage the possibility of using shared storage or disposal facilities through harmonized procedures.

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# Glossary

| | |
|---|---|
| ALARA | As low as reasonably achievable |
| ARAO | Agencija za radioaktivne odpadke, Agency for radioactive waste management in Republic of Slovenia |
| BAT | Best available technology |
| CHANCE | Characterisation of conditioned nuclear waste for its safe disposal in Europe |
| CMR | Carcinogenic, mutagen, toxic for reproduction |
| COVRA | De Centrale Organisatie Voor Radioactief Afval, is the sole company in the Netherlands tasked with collecting, processing and storing all radioactive waste |
| CS | Civil society |
| DBD | Deep Borehole Disposal |
| DD | Danish Decommissioning, a state enterprise for radioactive waste management in Denmark |
| DSRS | Disused Sealed Radioactive Sources |
| EURAD | European Joint Programme on Radioactive Waste Management |
| ERDO | European repository development organization |
| The Fund | An expert organization for the development of joint radioactive waste disposal and Krško NPP decommissioning programmes in Croatia |
| HARPERS | HARmoniced PracticEs, Regulations and Standards in waste management and decommissioning |
| HLW | High level waste |
| IAEA | International Atomic Energy Agency |
| ILW | Intermediate level waste |
| LILW | Low and intermediate level waste |
| LLW | Low level waste |
| Magnox | Magnesium non-oxidising |
| MICADO | Measurement and Instrumentation for Cleaning And Decommissioning Operations |
| MS | Member State |
| NCSRD | National Centre for Scientific Research Demokritos |
| NES | Nuclear Engineering Seibersdorf, Agency for radioactive waste management in Austria |
| NND | Norwegian Nuclear Decommissioning, an agency responsible for decommissioning of the research reactors and other nuclear infrastructure connected to this end. NND is also responsible for safe handling, storage and disposal of nuclear waste in Norway. |
| OECD-NEA | The Nuclear Energy Agency (NEA) within the Organization for Economic Co-operation and Development (OECD) |
| PREDIS | The pre-disposal management of radioactive waste-project |
| PSF | Particular spent fuel |

| | |
|---|---|
| ROUTES | Waste management routes in Europe from cradle to grave |
| RRSF | Research reactor spent fuel |
| RWM | Radioactive Waste Management |
| SF | Spent fuel |
| SHARE | StakeHolders-based Analysis of Research for Decommissioning |
| SIERS | Spent ion exchange resin |
| SIMS | Small inventory member state |
| SNF | Spent nuclear fuel |
| SOGIN | *Società Gestione Impianti Nucleari,* the State-owned company responsible for the decommissioning of Italian nuclear plants and for the management of radioactive waste |
| UNGG | Uranium Naturel Graphite Gaz |
| $UO_X$ SF | Uranium oxide spent fuel |
| VLLW | Very low level waste |
| WAC | Waste acceptance criteria |
| WM | Waste Management |
| WS | Workshop |

# 1. Introduction

Waste management routes in Europe from cradle to grave (ROUTES) WP9 is one of the strategic work packages in the European Joint Programme on Radioactive Waste Management (EURAD). The objectives of ROUTES are to:

- Provide an opportunity to share experience and knowledge on waste management routes between interested organisations (from different countries, with programmes at different stages of development, with different amounts and types of radioactive waste to manage).
- Identify safety-relevant issues and their R&D needs associated with the waste management routes (cradle to grave), including the management routes of legacy and historical waste, considering interdependencies between the routes.
- Describe and compare the different approaches to characterization, treatment and conditioning and to long-term waste management routes, and identify opportunities for collaboration between MS (Member-States).

The work of ROUTES is organized in 8 tasks:

- Task 1 – S/T coordination, State-of-the-art and training material
- Task 2 – Identify challenging wastes to be collaboratively tackled within EURAD
- Task 3 – Description and comparison of radwaste characterization approaches
- Task 4 – Identification of WAC used in EU Member-States for different disposal alternatives in order to inform development of WAC in countries without WAC/facilities
- Task 5 – RWM solutions for small amounts of wastes
- Task 6 – Shared solutions in European countries
- Task 7 – Interactions with Civil society
- Task 8 – ROUTES Extension on the evaluation of the possible waste management solutions for Member States without WAC and with small inventories

Task 6 within ROUTES focuses on:

- Describing and assessing knowledge on and approaches to sharing technology and facilities between MS.
- Providing an overview of the interest in and experience with sharing technology/facilities in the different steps of waste management.
- Identifying gaps and defining needs for R&D, strategic priorities and opportunities for collaboration between MS, as applied to challenging wastes as defined in Task 1 and early stage RWM programmes and Small Inventory Programmes.

These efforts include outcomes of relevant projects carried out in the frame of ERDO, NEA or IAEA, recognizing that not all MS can afford a national waste management solution. Opting not to build a characterization, treatment, conditioning, storage or disposal facility for a very small amount of radioactive waste and, instead, collaborating with other small inventory member states to share a facility or use already available commercial facilities might be an interesting path to investigate. Therefore, ROUTES Task 6 investigates the feasibility of shared European solutions for waste management from cradle to grave, based on past experiences and lessons learned. In EURAD (Deliverable n° 9.12) [1] an overview of ERDO, NEA and IAEA main results can be found. ERDO was originally concentrating on shared disposal options but has since widened the scope of their work on all the topics related to shared waste management solutions. IAEA and NEA have studied topics their members have expressed interest in e.g. scenarios for co-operation [2] or mobile facilities [3].

Task 6 comprises three subtasks and has so far produced two deliverables about the history of shared solutions in Europe: EURAD (Deliverable n° 9.12) [1] summarises studies and plans for developing shared solutions for radioactive waste management in Europe and EURAD (Deliverable n° 9.13) (in preparation) gathers case studies on shared solutions between Member states in different stages of the waste lifecycle.

The scope of this third Task 6 deliverable report is to summarise the results of ROUTES on shared solutions, providing input for future R&D needs within the context of shared solutions, organized by the contributing tasks and concluding with a summary of recommendations. Work of the other tasks (2-7) in

ROUTES, where options for shared solutions were identified (but were sometimes out of scope of those tasks) and input of participants in the ROUTES WSs was utilized to collect the information summarized in this report. When other projects had similar outcomes, they were also referred to.

# 2. Managing challenging wastes

## 2.1 Input from ROUTES Task 2

In EURAD (Deliverable n° 9.5)[5] – *Overview of issues related to challenging waste* in Task 2 of the ROUTES WP, the following challenging wastes were identified: sludges, spent ion exchange resins (SIERs), organic waste, bituminized waste, graphite, U/Th/Ra bearing waste, decommissioning waste, particular spent fuel, Disused Sealed Radioactive Sources (DSRS), waste containing reactive metals, and waste containing chemotoxic substances. This list of the 11 challenging waste types is of interest for both nuclear and non-nuclear countries. The most common challenging wastes were SIERs, DSRS, decommissioning waste and graphite waste.

As a first analysis of the main difficulties faced by the MS in the management of challenging waste, responses to the ROUTES questionnaire have indicated that lack of disposal routes (31%), characterization (22%) and issues related to conditioning or treatment (20%) are the primary challenges.

Regarding disposal route aspects, for many MS, the end state of the waste management strategy is not clearly defined, which leads to difficulties in developing treatment and conditioning techniques, as the packages produced may not be suitable for future facilities' Waste Acceptance Criteria (WAC). For characterization issues, a vicious circle has been pointed out in EURAD (Deliverable n° 9.5) [5]: not having a management route prevents prioritizing waste characterization and the lack of characterization prevents the identification of management routes. *Table 1 – Comparison of challenging wastes identified in ROUTES and in ERDO projects.* summarizes the waste types and difficulties related to them.

Waste containing asbestos and mercury were found to be also challenging wastes for many participants and solutions for those would be beneficial. It is important to keep in mind that good practices are needed for innovative treatments.

Difficulties in the management of decommissioning waste are related to the characterization, volume and retrieval issues, final disposal options (and regulatory aspects) as well as varied waste types e.g. construction materials, soils, scrap metal, wood, tools and safety equipment and even contaminated liquids. Decommissioning waste spans from material not contaminated at all, potentially contaminated, contaminated but treatable for clearance for reuse, recycling or conventional disposal. Decommissioning related issues have been handled in other European projects e.g. SHARE [6], MICADO [7], HARPERS [8] and to some extent in PREDIS [9], whereas ROUTES as a part of EURAD has only touched the issue. OECD-NEA has also provided guidance on decommissioning and dismantling e.g. in reports [10], [11] and [12].

## 2.2 Input from ERDO-projects

Since 2020 ERDO has undertaken two projects related to waste management in its member countries: the Deep Borehole Disposal-project [13], mostly focusing on assessing High Level Waste (HLW) and Long Lived Low and Intermediate Level (LILW-LL) inventories of participating ERDO countries, and the Legacy Waste Characterization-project[14], which assessed Low and Intermediate Level Waste (LILW) inventories of participating ERDO members. Both projects started with an assessment of the inventories, allowing for some comparison to ROUTES results. Participants in the legacy waste project included NES (Austria), Fund (Croatia), DEKOM (Denmark), NCSRD (Greece), SOGIN (Italy), COVRA (Netherlands) and NND (Norway), with Italy, Croatia and Norway not represented in the ROUTES project.

The survey and the relevant analysis revealed many similarities in the declared data of legacy waste streams and their envisaged future management. In particular, 8 out of 13 groups (DSRS, solid mixed waste, powdery waste, sludges, ion exchange resins, graphite, alpha bearing solid waste, chemotoxic materials) are common to at least 4 out of 7 countries. The lack or the low reliability of the radiological characterization (more than 80% of the streams effectively need re-characterization) make the classification of these waste streams quite difficult. The planned characterization methodology for more than 40% of these streams has yet to be defined, while the remaining streams are planned to be characterized during the following sorting and treatment phases. Notwithstanding such uncertainties, more than 50% of the waste streams are declared as Intermediate Level Waste (ILW) unsuitable for near-surface disposal (possibly due to the expected concentration of long-lived radionuclides). In a few cases the legacy waste streams have been conditioned according to obsolete rules and will require re-treatment and re-conditioning for complying with WAC when available. In all other cases the waste is simply packaged in raw (or pre-treated) conditions but the future treatment and conditioning activities are defined (mainly in the concept implementation phase) for less than 50% of the streams, the remaining declared as 'not defined' or 'to be defined' [19]. The lack of information about the predisposal activities performed on the waste is another important common issue among the MS.

The most important result of the survey is that many waste streams present strong similarities among countries and this, coupled with the small quantities of waste and the common needs of characterization and treatment/re-treatment for disposal, makes these waste streams for collaboration, at least in pre-disposal management routes. Further chances of knowledge sharing or even pre-disposal facility sharing are identified in R&D European project (PREDIS [9]) these are innovative treatment processes on specific waste streams and the realization of a transportable in-drum grouting station declared by some countries.

The next 'steps to sharing' are therefore strongly connected to the implementation of a bilateral and/or multilateral information exchange and an agreement between organizations managing similar waste streams with common pre-disposal needs.

In *Table 1 – Comparison of challenging wastes identified in ROUTES and in ERDO projects.* the waste types and challenges related to them are summarized.

## 2.3 Summary and recommendations for challenging waste management

ERDO members reported some challenging legacy waste streams which are partly similar to those of ROUTES. Joint challenging waste streams were sludges, graphite, PSF, DSRS, reactive metals, chemotoxic substances, SIERs and organic wastes (both solid and liquid). Challenges regarding these waste types were often characterization, treatment and disposal routes, the same as reported in ROUTES Task 2 [5]. *Table 1 – Comparison of challenging wastes identified in ROUTES and in ERDO projects.* presents a comparison of the difficulties related to challenging wastes reported in ROUTES and in ERDO.

Regarding treatment and conditioning, MS are still awaiting the development of innovative techniques for a number of challenging waste types: graphite, waste containing reactive metals, organic waste, etc. Initiatives regarding the management of those challenging wastes have been implemented in some countries, and there is interest in sharing these good practices. PREDIS has provided information on all of these topics [9]. However, these new techniques raise R&D issues about, for instance, the lifespan of the innovative matrices that could be used. Similarly, an interest in the sharing of mobile treatment facilities between countries has also been highlighted by some MS, particularly regarding treatment of sludges and resins. MICADO [7] has concentrated on information about technical aspects of mobile facilities and HARPERS [8] on regulatory aspects.

In addition there are synergies with the same challenging waste types found in several countries, and the challenges are often similar, related to characterization, treatment, conditioning or disposal methods needed. This creates opportunities for shared facilities.

Resins and sludge were especially recommended for further R&D studies. However, continued sharing of innovative technologies among countries is highly encouraged also in other topics.

*Table 1 – Comparison of challenging wastes identified in ROUTES and in ERDO projects.*

| **Waste type** | **EURAD-ROUTES** [5] | **ERDO**[13],[14] |
|---|---|---|
| Sludges | 10 MS are experiencing difficulties in the management of sludge. These difficulties are mainly related to characterization and conditioning or treatment issues. | 5 out of 7 countries find this waste type challenging. Challenges were related to characterization. |
| Bituminized waste | 5 MS are experiencing difficulties in the management of bituminized waste. The difficulties are mainly related to disposal, reactive/corrosive constituents and suitable packaging, characterization issues, conditioning or treatment and WAC issues. | |
| Graphite | 15 MS are facing difficulties in the management of graphite waste. The difficulties are mainly related to the availability of final disposal options, organisational aspects/lack of knowledge and conditioning and treatment issues. | This waste group is common to 4 out of 7 countries. Characterization of the graphite was listed as a challenge. |
| U/Th/Ra bearing waste | 9 MS are facing difficulties in managing Ra/Th/U bearing waste Among the difficulties raised by the countries, the major issues are related to the lack of disposal options, characterization and treatment/conditioning issues. | |
| (PSFs)include all non-$UO_X$ SF, Magnox SF, Al-cladding, SF used in former UNGG reactors, or RRSF | 5 MS are facing difficulties with the management of PSFs. More precisely, these difficulties are mainly related to the lack of available facilities for some of the considered treatment/conditioning options, for pre-disposal handling or for final disposal. | Some ERDO members have in their inventories small amounts of HLW. GDF for these amounts would not be economical solutions, so other disposal routes have been researched. |

| **Waste type** | **EURAD-ROUTES** | **ERDO** |
|---|---|---|
| DSRS | 14 MS are experiencing difficulties in the management of DSRS and those difficulties are mainly related to disposal- and characterization issues. | Common challenge to 5 out of 7 countries. The reliability of the radiological characterization, when available, is generally reported as 'low' or 'medium' and this may create difficulties in checks for compliance with WAC. |
| Metals (Consisting of parts of the fuel elements, internal instrumentation of the reactor or objects contaminated with plutonium.) | Not addressed in EURAD-ROUTES Task 2 | Common to 3 out of 7 countries, includes activated and contaminated metals. Radiological characterization is missing or at low realiability. Chemical characterization has to be implemented by all countries in order to take into account possible toxic metals (e.g., Pb) and degrading metals (e.g., Al) before defining the most suitable conditioning process. |
| Waste containing reactive metals<br><br>These waste can include a wide range of metals, e.g., Al, Be, Mg, etc. | 12 MS are facing difficulties in the management of waste containing reactive metals. These difficulties were related to disposal issues, treatment and conditioning issues and characterization aspects. | Common to 2 out of 7 countries. These difficulties were related to disposal issues, treatment and conditioning issues and characterization aspects. |
| Chemotoxic substances (e.g., asbestos, Cd, Hg, Be, etc.). | 12 MS are facing difficulties managing waste containing chemotoxic substances. There are major issues related to treatment and conditioning, characterization, and disposal. | Common to 5 out of 7 countries. Both radiological and chemical characterization of these waste are lacking or poor; moreover in many cases the future treatment is not reported, probably due to the presence of toxic materials. |
| Mixed solid waste (Variety of waste streams containing diverse solid materials) | Not addressed in EURAD-ROUTES Task 2 | This group, common to 6 out of 7 countries. Characterization is often reported with 'low' reliability level. Characterization difficulties are also due to waste heterogeneity within the same container, which makes sorting, waste treatment and checking for compliance with WAC even more difficult. |

| **Waste type** | **EURAD-ROUTES** | **ERDO** |
|---|---|---|
| Powdery waste (e.g. contaminated soil, metals, ashes and zeolites) | Not addressed in EURAD-ROUTES Task 2 | Common to 4 out of 7 countries. Waste is not always characterized and the reliability of the characterization is ‘low’. The alpha emitters content in some waste streams could invalidate the current declared classification. The treatment and/or conditioning processes are not always envisaged. |
| SIERs | 13 MS are facing difficulties with managing SIERs. Issues are related to the treatment, conditioning and characterization of SIERs | Common to 5 over 7 countries. In most countries the radiological characterization is at ‘low’ level of reliability and suitable sampling/characterization is foreseen. Chemical characterization is missing too. Difficulties are linked to the need of recovering the SIERs in the cases where they are already immobilized. |
| Organic wastes (solid and liquid) | 12 MS are experiencing difficulties in the management of organic waste. The difficulties are mainly related to conditioning or treatment issues, characterization issues, lack of disposal and volume and retrieval issues. | 3 out of 7 countries found solid or liquid organic wastes challenging. Problems were related to characterization issues. E.g. biological specimens, wood, PVC, heterogeneous liquid waste and organic liquids contaminated with plutonium or irradiated uranium, were listed among challenging waste types. |
| Alpha bearing solid waste e.g. Materials contaminated by radium, thorium, plutonium and irradiated/non irradiated uranium | Not addressed in EURAD-ROUTES Task 2 | Common to 5 out of 7 countries. Challenges related to treatment and conditioning due to lack of characterization. |
| Liquid waste | Not addressed in EURAD-ROUTES Task 2 | Common to 3 out of 7 countries, includes liquid waste from various sources containing various radionuclides (Alpha, beta and gamma emitters). Problems were related to characterization issues. |

# 3. Waste characterization

## 3.1 Input from ROUTES Task 3

Task 3 on radioanalytical characterization of radioactive waste and waste with toxic properties, reported in (Deliverable n° 9.7) **Erreur ! Source du renvoi introuvable.** obstacles for successful characterization were identified: representative sampling and improvement and validation of scaling factors. SIMS, as Greece or Portugal, indicated that they lack the human and financial resources to implement the characterisation of their radioactive waste, particularly regarding decommissioning. This is primarily due to the fact that some measurement equipment requires specific knowledge and training.

Consequently, the possibility of setting up an R&D programme on characterization equipment, applicable to handle legacy waste, that can be shared and transported between countries was suggested. Another topic useful for sharing was identified to be a common approach to sampling.

## 3.2 Input from ERDO activities

ERDO's Legacy waste characterization project Task 4 assessed the physical, chemical and radiological characterization of Very Low Level Waste (VLLW) and Low Level Waste (LLW) inventories reported by the participants. Intermediate Level Waste (ILW) and High Level Waste (HLW), unsuitable for near-surface repository, were not considered [16]. Large parts of this waste is stored in interim facilities, often in production sites, as NPPs, ranging in ages from just a few years to several decades. In many cases the foreseen storage time is not yet known due to lack of appropriate disposal plans. Indications about chemical, physical, radiological characterization techniques and approaches of each technique were described in the report, as well as their advantages and disadvantages.

A survey conducted among seven ERDO and non-ERDO countries (Austria, Croatia, Denmark, Greece, Italy, Netherlands, Norway and Slovenia) aimed to analyze small inventories of legacy waste generated to date, along with their main characteristics (radiological, physical, chemical and mechanical). The results indicated that waste streams show strong similarities among countries, pointing out common needs about waste characterization, but also pointing out indication about the necessity of common/shared WACs.
The conclusions obtained from this work cannot be considered definitive and exhaustive to solve the common problem of legacy waste management (in particular regarding their characterization). A further joint effort is needed in the field of research, especially in the field of characterization techniques.

Challenges related to the management of legacy waste are shared by many countries, with different approaches and applied standards. For ERDO these kinds of pre-disposal activities can be considered a part of a long term strategy, representing a first step to develop a common system possible to apply in the future in a shared disposal facility.

## 3.3 Summary and recommendations for waste characterization

A further joint effort is needed in the field of research, especially in the field of characterization techniques, in order to reduce the limits (e.g. limitations in sample geometry or radionuclides with little-to-none gamma emission) that are still present in current technologies. The possibility of setting up an R&D programme on radiological characterization equipment that can be shared and transported between countries was suggested as one possibility to improve SIMS capabilities to characterize their waste in the ROUTES WS. (Recommendation R&D-1, Development of a mobile facility for RAW characterization, treatment or conditioning) [17]**Erreur ! Source du renvoi introuvable.**. EU-projects CHANCE, MICADO and PREDIS in their joint paper also noted the importance of mobile measurement systems [18]. Any joint efforts in characterization may also help to take first steps towards radioactive waste disposal in shared or national facilities.

# 4. Waste Acceptance Criteria

## 4.1 ROUTES input

Task 4 of ROUTES identified in their Deliverable n° 9.9 [19] several topics where improvements are needed. Topics listed below are either suitable for shared solutions or can enhance the further development of shared solutions:

- Mobile systems and other shared approaches to waste characterization
- Approach to manage challenging wastes with properties that do not meet WAC for existing or planned facilities
- Comparison and standardisation of radionuclides (and their speciation) to take into account in waste characterisation and WAC, including $^{14}C$
- Comparison and standardisation of physical / chemical waste characteristics to take into account in waste characterization and WAC
- Shared / harmonized approaches regarding regulations and/or WAC across different countries (to the extent that this is achievable), also taking into account non-radiological regulations (e.g. for hazardous / toxic wastes) if applicable
- Collaboration with other Member States to provide training and sustain competences in the field of radioactive waste management

Other topics mentioned were sharing of waste management facilities in general (fixed, modular or mobile options).

## 4.2 ERDO input

The high-level objective of the ERDO Legacy Waste Characterization (LWC) project was sharing information and methodologies for a better characterization of legacy waste regarding possible future management activities and its further acceptance as waste in a disposal facility. One aim of the project was to derive a common minimum set of WACs [20], [21] for VLLW-LLW streams for a near-surface disposal.

LWC project collected information about the WACs through a questionnaire, which was divided into seven categories (Radiological, Chemical, Physical, Mechanical, Thermal, Biological, Packaging and Labelling). Later the chosen categories were reduced to four (radiological, chemical, mechanical, others/physical). Since only Croatia and Spain could provide information, in order to increase the information about WACs, other sources, such as the documentation of some international working groups (e.g. ROUTES and PREDIS) or other published documentation were reviewed.

Information was also gathered from documents collected from various sources and/or free published documents and at the end information were gathered for 18 countries: Belgium, Bulgaria, Romania, Spain, France, Iran, Lithuania, Canada (Ontario), Australia (Sandy Ridge), Germany, Poland, Hungary, Czech Republic, Croatia, United Kingdom, Switzerland, Slovakia and Italy. A brief overview of the results is below, more detailed information can be found in the original report [20][20].

<u>Radiological characteristics:</u>

Radiological WACs focus on limiting the activity concentration values and the total activity, especially for specific radionuclides. Limits in each country vary based on national classification, site safety assessment and accidental scenarios studied. The radiological limits are set based on the type of radionuclide both for waste package and for the repository site or just for the waste package.

<u>Chemical characteristics:</u>

Chemical WACs concentrate on chemicals which could affect the stability of the radiological containment barriers and limitation of toxic/harmful elements and complexing agents content to avoid risks for the safety of the population and the environment. Most of the WACs concern the limitation of chemical elements and complexing agents that can degrade the waste matrix or package. Explosive, corrosive, oxidizing, flammable, strongly reactive and gas producing materials are also limited or forbidden.

In some countries, current regulations lacks directives about the management of radioactive waste containing hazardous, biological, pathogenic or infectious agents. Therefore, in these cases treating and conditioning of such waste are forbidden in radioactive waste facilities. In other countries they must be treated, conditioned and packed in a way that minimizes the hazard.

Some countries do not allow mixing of different materials within the same waste package, in others some categories of materials can be inserted in limited quantities or subjected to special treatments before disposal. In Annex A of [20] these differences are explained in detail. Some countries require an inventory of the CMR substances (carcinogenic, mutagen, toxic for reproduction) present in the waste.

Mechanical characteristics:

The conditioning matrix, the container and the waste form must form and keep a stable package over time, to be considered suitable for disposal. There are therefore minimum acceptance criteria for the compression resistance of concrete and in some cases also for tensile strength of the concrete container.

Metal containers and waste package should withstand external fire and be resistant to corrosion.

Waste forms (the physical form of the waste following treatment / conditioning) must be physically solid and stable, non-reactive and non-flammable, and resistant to degradation.

Other characteristics:

All waste packages must be identifiable, therefore a series of characterisation items (e.g. labels, colours, identification codes) are required.

The amount of liquids accepted for waste packages were between 0-3% by volume and there are also limits regarding voids in the waste package.

The research carried out lead to a suggested minimum set of WACs for radiological, chemical, mechanical and physical characteristics, but it also highlighted a lack of homogeneity in the information on the WACs adopted by the different countries.

## 4.3 Summary and recommendations on WACs

Common understanding/harmonized approaches to WACs was one of the topics identified as a need by both ERDO and ROUTES work. This was also highlighted during the ROUTES WS on R&D recommendations (the MS337 – ROUTES – Workshop on R&D recommendations) and lead to Recommendation StSt-10 - Benchmarking Exercise for WAC Development [17].

The aspect harmonization of practices, methodologies and approaches in the field of decommissioning and waste management was also discussed in HARPERS engagement sessions with stakeholders. One of the conclusions was to promote harmonized criteria and regulations (policies) to enable re-use and recycling, preserve natural resources and minimising the waste to be disposed of **Erreur ! Source du renvoi introuvable.**.

# 5. Disposal methods for SIMS

## 5.1 Input from ROUTES

In ROUTES Deliverable n° 9.10 [23], an aggregation of existing knowledge on diverse disposal options for small amounts of waste was compiled. For SIMS, which generate only a relatively limited amount of waste from medicine, industry and research, including Research Reactors (RRs) and/or Nuclear Power Plants (NPPs), disposing of their small inventory could be challenging. Disposal solutions for large inventories might not be economically viable or scalable. The report outlined three possible combinations of disposal solutions that could be suitable for SIMS, encompassing:

i) complementary near surface disposal concepts,
ii) combination of silos and tunnels with galleries and boreholes and
iii) a combination of very deep boreholes and other disposal options.

Each of these configurations could be considered also as shared facilities. Before disposal, the volume of radioactive waste should be minimised, e.g. by incineration, melting and reuse, or when possible by clearance.

## 5.2 Input from ERDO

In ERDO, the potential offered by Deep Borehole Disposal (DBD) concept for small inventories and shared option was acknowledged, and a significant R&D effort took place from 2019 to 2022 under the Deep Borehole Disposal project. In this project, Slovenia, Croatia, the Netherlands, Denmark and Austria collaborated to assess which parts of their inventories were suitable for borehole disposal. Some inventories proved impractical due to their size or the use of large containers used for their packaging, but for some inventories DBD was found to be a suitable disposal option [13].

The main findings of the project were the following:

- *DBD is a technologically feasible and potentially cost-efficient solution for high-level or long-lived intermediate level waste from Croatia, Slovenia, Denmark, The Netherlands, and Norway.*
- *A multinational DBD-repository is likely to be more cost-effective than separate national DBD repositories.*
- *Borehole disposal of LILW could be of interest for very small inventories of LILW, or specific sub-categories of LILW. Specifically, it could be of interest for the Austrian inventory of long-lived LILW.*

However DBD is not as well developed as disposal option as mined Deep Geological Repositories (DGR) and further research is needed to develop the DBD concept to the same level as DGRs are (e.g. in France, Finland and Sweden). Some recommendations for future work were made:

- *Conduct a full-scale demonstration encompassing site characterization, drilling, waste emplacement, and borehole sealing, supported by a safety case developed in line with international guidelines and best practices. This would enhance confidence in DBD and identify priorities for further development and demonstration work.*
- *Increase the adaption of DBD to site- and waste-specific characteristics. Given that DBD is a less mature concept than mined repositories, its development can catch up only if DBD becomes an integral part of a national or multinational disposal program in the same way as mined repositories have been developed in several countries over several decades (e.g. in Finland, Sweden, Canada, France and others).*

## 5.3 Summary of disposal options for SIMS

DBD concept, if developed to the level where safety could be demonstrated, could be a viable solution for many SIMS. Also there are two possible options to implement it, as a shared DBD facility or shared mobile equipments and team to construct national DBD facilities in countries where it is needed.

One of the recommendations during the ROUTES WS on R&D (the MS337 – ROUTES – Workshop on R&D recommendations [17]) was to develop a guidance for the implementation of deep borehole disposal, including their safety case development [13]**Erreur ! Source du renvoi introuvable.**. Recommendation KM-3 Development of guidance for the implementation of deep borehole disposal, including their safety case development. Also the IAEA has acknowledged the potential [24] and need for further development of DBD concept and Coordinated Research Project is under development [25],[26].

It is worth noting that IAEA is also supporting work on borehole disposal for sealed radioactive sources. The IAEA is providing technological and engineering support for the first of a kind construction and implementation of borehole disposal facilities for radioactive waste, as part of a pilot project underway in Malaysia and Ghana, project is funded by Canada [27].

There is already at least one company working towards commercial DBD solution, Deep Isolation [28].

# 6. Shared solutions case studies

In ROUTES Deliverable n° 9.13 [4], case studies of examples of shared solution were compiled. The lessons learned from this are the following:

- It was noticed that the time needed for the paperwork to set up a first collaboration for e.g. RAW treatment between MS could be particularly long. A good teamwork and confidence between involved partners increased the success of new collaboration and decreased the difficulty of the approach. Examples can be found in the Appendix A of [4] case studies e.g. UK metallic wastes for melting by Cyclife Sweden AB and Management of radioactive waste at the NPP Krško**,** The complexity of procedures needed to set up international collaboration could also lead to the set up time being long.
- For some collaborations an intergovernmental agreement in addition to a commercial agreement is needed. The success of collaborations which require an intergovernmental agreement depend on the good political relationship between involved MSs. In the cases where political agreement is needed there is also possibility of unpredictable stop because of political changes in participating states.
- The public consultation and acceptance are important in order to ensure the durability of agreements between countries.
- The involvement of tiers in the preparation of a collaboration about SNF reprocessing increase the international confidence about SNF transfer transparency.

# 7. CS input on shared solutions

In the ROUTES Task 6.3 WS, Task 7 participants gave a presentation about ethics for RWM shared solutions and presented 3 case studies. They are also presented in Deliverable n° 9.16 [29]**Erreur ! Source du renvoi introuvable.**. Their first and foremost objective is to achieve a level playing field for the collaborators. This is to prevent the development and localisation of shared facilities towards countries with the lowest environmental and social standards. Any bilateral, multilateral, European and international cooperation on planning, constructing, operating and closing of shared nuclear facilities, must involve partners that follow the same technical, legal and ethical standards in their home countries.

Generally, shared solutions regarding technologies are not considered a problem if they are based on BAT ("best available technology") or ALARA ("as low as reasonable achievable") principles, in the context of international safety standard.

Apart from public acceptance, other challenging topics mentioned for shared solutions would be harmonizing national policies, how to do cost sharing fairly, political guidance and regulatory compliance.

Although IAEA has addressed some of these challenges in its publications (e.g., on cost sharing), implementing these principles in practice is a different matter. The decision-making process could in principle mirror that of a national facility, with participating countries simply agreeing on the process beforehand. Examples of conditions/criteria and governance can be found in IAEA reports such as *Multilateral Approaches to the Nuclear Fuel Cycle Expert Group Report to the Director General of the IAEA [30]* and *Framework and Challenges for Initiating Multinational Cooperation for the Development of a Radioactive Waste Repository [31].*

# 8. Feasibility of shared solutions

As described in chapter 2, members of both ROUTES and ERDO projects reported some challenging legacy waste streams which are partly similar. Joint challenging waste streams were sludges, graphite, PSF, DSRS, reactive metals, chemotoxic substances, SIERs and organic wastes (both solid and liquid). Challenges to these wastes were often lack of characterization, treatment and disposal routes. The relatively small volumes associated to these waste streams make them suitable for collaborative waste management solutions.

A particular interest emerged in the potential sharing of mobile treatment facilities, particularly for addressing challenges related to the treatment of sludges and resins. Representative sampling was also identified as a significant obstacle for successful waste characterization. SIMS, indicated resource constraints, notably to implement the characterization of their radioactive waste for decommissioning, due to the need for specific knowledge and training. Consequently, the possibility of setting up an R&D programme on radiological characterization equipment that can be shared and transported between countries was discussed. This leads to the recommendation to develop a mobile facility for radioactive waste characterization, treatment or conditioning (ROUTES recommendation R&D-1) [17].

Even though several topics of common interest and suitable for shared solutions were identified, practical bottlenecks were also recognized: standard procedures, common understanding of WACs and harmonized regulations, were highlighted as topics which needed further development to achieve effective shared solutions. This was also recognized in ROUTES Recommendation StSt-10 - Benchmarking Exercise for WAC Development [17]. Lack of harmonization of regulatory aspects was identified as one of the most difficult barriers stopping cross border services in HARPERS Webinar **Erreur ! Source du renvoi introuvable.**.

It is notably evident that sharing predisposal and disposal facilities need important work in regulatory and waste management procedures harmonization. While technical research is needed, the advancement of shared solutions relies heavily on political decisions.

In this societal-political context, it is important to keep in mind civil society (CS) task input to achieve a level playing field for the collaborators and lessons learned from case studies showing the importance of public consultation. This consideration leads to the recommendation to “harmonize procedures to facilitate collaboration between member states” (ROUTES recommendation StSt-3 [17]), aiming at clarifying the complexities associated with determining the necessary procedures, including public consultation, and permits, which can be both time-consuming and resource-intensive. Public acceptance was also identified in HARPERS as a barrier stopping cross border services [22].

Simplifying this process requires harmonizing the various steps needed to enhance the possibility of operating commercial treatment facilities outside national borders, help reducing storage periods and improve safety, and encourage the possibility of using shared storage or disposal facilities through harmonized procedures.

# 9. References


[1] Vuorio, M. (2022). *A review of past and present studies and plans for developing shared solutions for radioactive waste management in Europe.* Deliverable D9.12 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[2] IAEA. (2004). *Developing multinational radioactive waste repositories: Infrastructural framework and scenarios of co-operation IAEA-TECDOC-1413.* Vienna: IAEA.

[3] OECD NEA. (2017). Radioactive Waste Management*, Recycling and Reuse of Materials Arising from the Decommissioning of Nuclear Facilities*, No. 7310 . France: OECD NEA.

[4] Rooses, A., Germany, J., *Case studies on shared solution between Member states***,** Deliverable D9.13 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[5] Wasselin V., M. M. (2022). *Overview of issues related to challenging wastes.* Final version as of 18.08.2022 of deliverable D9.5 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[6] SHARE. (2024, May 3). SHARE. https://shareh2020.eu/.

[7] MICADO. (2024, May 3).MICADO. https://www.micado-project.eu/.

[8] HARPERS. (2024, May 3). HARPERS. https://www.harpers-h2020.eu/.

[9] PREDIS. (2023, May 30). *PREDIS*. Retrieved from EU-Project PREDIS: https://predis-h2020.eu/.

[10] OECD NEA. (2013). Radiological Characterisation for Decommissioning of Nuclear Installations, Final Report.

[11] OECD NEA. (2017). Radiological Characterisation from a Waste and Materials End-State Perspective, Report No. 7373.

[12] OECD NEA. (2018). Preparing for Decommissioning During Operation and After Final Shutdown, Report No. 7374.

[13] Kristiansen, H. R. Rapić, A., Sjølin Thomsen, H., Kegel, L., Vuorio, M., Neckel, W., (2022). *Boreholes as a permanent solution for ERDO Association*.

[14] Sogin. (2021). *Technical Note ERDO-WG – LWC project – Task 1 Report on main Legacy Waste streams in the interested countries.*

[15] Bornhoeft M.C., Gascon J., Millot L., Paiva I., Alves, J., Savidou A., Bielen A., Kutina I., Soloviov A.,Slugen V., Ivanov I., Paschalidis I., Pritrsky J. (2023): ROUTES – Review of radioanalytical characterisation of selected radioactive wastes and wastes with complex chemical and toxic properties. Final version as of 30.05.2023 of deliverable D9.7 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[16] ENEA. (2022). *Legacy waste characterization project – task 4: Characterization techniques of radioactive legacy waste.* ENEA / ERDO Association.

[17] IRSN. (2022) *ROUTES – Workshop on R&D recommendations*, MS337 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593

[18] Morichi, M., Fanchini, E., Breuil, E., Bruggeman, C., Perot, B., Ricard, D., Niederleithinger, E. Developments and experiences of the CHANCE, MICADO and PREDIS projects in radioactive waste characterization, *EPJ Nuclear Sci. Technol.* 9, 12 (2023).

[19] De Bock, C., Harvey, L., Harrison, T. (2023). Suggestions for the management of challenging wastes while maintaining compatibility with options for disposal: ROUTES Task 4 Final Report,

Final version as of 15/12/2023 of deliverable D9.9 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[20] Sogin. (2022). *Technical Note ERDO - LWC project – Task2 – Minimum set of WACs for near-surface disposal of VLLW-LLW.*

[21] Sogin. (2023). *Technical Note ERDO – LWC project Final Report.*

[22] Maes, M., Oxberry, D., Pancotti, F., Banford, A., Szőke, R., Jacops, E. Presentations from HARPERS online stakeholder feedback meeting (May 30th 2023). https://www.harpers-h2020.eu/component/jdownloads/?task=download.send&id=240&Itemid=1518.

[23] Feinhals J., Miksova J., Savidou A, Coninx St., Bornhöft M. C., Vojtechova H., Langegger E., Beyerknecht R., Bracke G., Cizelj L., Tomić M., Wolf J, Paiva I., Zakrzewska-Kołtuniewicz G., Kaissas I., Baptista A. (2023): *Collection and Analysis of Actual Existing Knowledge about Disposal Options for SIMS*. Final Version as of 17.05.2023 of deliverable D9.10 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[24] IAEA. (2020). *Underground Disposal Concepts for Small Inventories of Intermediate and High Level Radioactive Waste*, IAEA-TECDOC-1934, Vienna.

[25] IAEA. (2024, March 13). Deep Borehole Disposal Options, https://www.iaea.org/projects/crp/t22003

[26] IAEA. (2024, March 13). New CRP: Enhancing Global Knowledge on Deep Borehole Disposal for Nuclear Waste (T22003), https://www.iaea.org/newscenter/news/new-crp-enhancing-global-knowledge-on-deep-borehole-disposal-for-nuclear-waste-t22003.

[27] IAEA. (2024 April 8). https://www.iaea.org/newscenter/news/malaysia-and-ghana-at-the-forefront-of-borehole-disposal-of-sealed-radioactive-sources

[28] Deep Isolation. (2023, May 30). https://www.deepisolation.com/

[29] Zeleznik N., Swahn J., Haverkamp J., Hooge N.H., Rey H., Daniska M. (2021): *Implementation of ROUTES action plan first phase*. Final version as of 04/05/2022 of deliverable D9.16 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

[30] IAEA. (2005). *Multilateral Approaches to the Nuclear Fuel Cycle Expert Group Report to the Director General of the IAEA.* Vienna: IAEA.

[31] IAEA. (2016). *Framework and Challenges for Initiating Multinational Cooperation for the Development of a Radioactive Waste Repository.* Vienna: IAEA.