Deliverable 1.9:

Update of the EURAD Strategic Research and Knowledge Management Agenda (SRA)

The EURAD SRA 2023

Work Package 1

This project has received funding from the European Union's Horizon 2020 research and innovation programme 2014-2018 under grant agreement N°847593.

http://www.ejp-eurad.eu/

Document information

Project Acronym	**EURAD**
Project Title	**European Joint Programme on Radioactive Waste Management**
Project Type	**European Joint Programme (EJP)**
EC grant agreement No.	**847593**
Project starting / end date	**1st June 2019 – 30 May 2024**
Work Package No.	**1**
Work Package Title	**Project Management Office**
Work Package Acronym	**WP1 PMO**
Deliverable No.	**1.9**
Deliverable Title	**Update of the EURAD Strategic Research and Knowledge Management Agenda (SRA)**
Lead Beneficiary	**ANDRA**
Contractual Delivery Date	**January 2023**
Actual Delivery Date	**March 2023**
Type	**Report**
Dissemination level	**PU**
Authors	**EURAD Bureau**

To be cited as:

EURAD Bureau. (2023): Update of the EURAD Strategic Research and Knowledge Management Agenda (SRA), of deliverable D1.9 of the HORIZON 2020 project EURAD. EC Grant agreement no: 847593.

Acknowledgement

This document is a deliverable of the European Joint Programme on Radioactive Waste Management (EURAD). EURAD has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 847593.

Status of deliverable		
	By	Date
Delivered (Lead Beneficiary)	EURAD Bureau (2022-2023), with support from the EURAD PMO and the EC PREDIS Project SRA Team.	02/03/2023
Verified (WP Leader)	V. Detilleux (Bureau Chair), L. Théodon (EURAD Coordinator)	07/03/2023
Reviewed (Reviewers)	A. Banford, D. Bosbach, C. Bruggeman, G, Buckau, C. Bucur, V. Detilleux, A. Geisler-Roblin, A. Göbel, B. Grambow, J. Hansen, E. Holt, A. Kontula, S. Schumacher, M. Van Geet, A. Waring, and P. Zuidema.	01/02/2023 to 20/02/2023 (first review) by all named reviewers 01/03/2023 to 07/03/2023 (final review) by each College representative
Additional Review	J. Hansen, A. Kontula A. Göbel, C. Bruggeman E. Holt, A. Göbel, D. Bosbach, P. Zuidema, C. Debayle	13/03/2023 14/03/2023 21/03/2023
Editorial	T. Beattie	29/03/2023
Approved (Bureau)	EURAD Bureau	31/03/2023
Submitted to EC (Coordinator)	Andra	04/04/2023

Executive Summary

Background

The EU Member States, through the EU's Competitiveness Council and research and higher education ministers endorsed, in December 2008, a new concept of research collaboration: Joint Programming. This was defined as a process by which countries would develop common visions and strategic research agendas in order to address major societal but also scientific-technical challenges. The EU Joint Programme on Radioactive Waste Management (EURAD) was established in June 2019 to complement the national efforts and enables effective use of resources by fostering and strengthening research development and demonstration collaboration. As of today, 51 organisations and 23 countries have come together to develop and implement this new approach. It comprises the implementer, the regulatory expertise function, and those with scientific and technical responsibilities and a national mandate for research and development in radioactive waste management in their respective countries. The first strategic research agenda of EURAD was established as a Founding Document of EURAD, first published in June 2019. It built on the work of the EC JOPRAD Project and good practice from other successful European Joint Programmes.

Purpose

The Bureau of the EURAD General Assembly is notably responsible for preparing an update of the EURAD SRA during 2022-23 – the output is entitled the EURAD SRA 2023. This update fundamentally serves two purposes, (i) to take stock and reflect on progress made since 2019 and capture emerging needs from across the Colleges (…what has changed, what is new…), and (ii) to prepare as an input for a potential future EC joint programme or partnership (...what should we work on together in the future beyond 2024+…).

The EURAD SRA 2023 continues to complement national programmes, by identifying activities of joint interest between European Waste Management Organisations (WMOs), Technical Safety Organisations (TSOs) and Research Entities (REs), where there is added value at the European level, compared with conducting activities at the national level. It builds on existing networks, coordination activities and initiatives. In particular it builds on the work established in EURAD and the EC PREDIS project.

Strategic Research and Knowledge Management Agenda (SRA)

The EURAD SRA 2023 has been developed purposely with the aim to present a holistic, integrated view on identified needs of common interest that may require research, development and demonstration (RD&D), strategic studies (think tank), and/or knowledge management activities along the whole chain of radioactive waste management, from cradle to grave. The updated full title of the EURAD SRA 2023 reflects this broad scope, so too does it alignment to the structure of the EURAD Roadmap, thus providing a more comprehensive view of all activities needed to implement a Deep Geological Repository (DGR) programme, not only focussing on RD&D.

Identifying drivers and priorities

To make the SRA more useful for future definition of work packages, we have characterised all identified needs using a common set of drivers. This helps to make the SRA more focused on the 'what' we could do and 'why'. The use of drivers replaces the classification scheme of high, medium and low priority scores previously used in the EURAD SRA 2019.

Table of content

Foreword

The EURAD community brings together, within its 3 Colleges (Waste Management Organisations, Technical Safety Organisations, and Research Entities), the main European stakeholders in long-term radioactive waste management around a common programme of research and development activities, strategic studies, and knowledge management. The EURAD Bureau represents the interests of the 3 Colleges and coordinates the strategic developments of the project.

One of the strategic milestones of EURAD is the update of its Strategic Research and Knowledge Management Agenda (SRA). This SRA is the basis of the joint programme as it paves the way for deploying new joint activities during the next EURAD implementation phases.

The SRA update process was developed and organised by the Bureau, in close collaboration with the EURAD Project Management Office and the organisations coordinating the Colleges (EURADSCIENCE, IGD-TP and the SITEX Network for the RE, WMO and TSO Colleges, respectively). A consensus building approach was followed, involving the 3 Colleges of EURAD and representatives of the PREDIS project. Views from Waste Generators and Civil Society Organisations were also considered in this process.

This exercise was a major challenge for the EURAD Bureau and the Colleges. It was probably the most intense joint programming activity of EURAD, as it required a delicate consensus on the strategic needs of the actors for the future, including the identification of joint drivers behind these needs, respecting the EURAD vision and Roadmap, and considering the advancement of waste management programmes in Member States.

The present SRA update reaffirms the willingness of the EURAD Colleges to work together, while respecting the independence of their missions, for the future of EURAD. This success gives confidence in EURAD's ability to meet its next major challenges, such as the preparation and implementation of a second EURAD implementation phase.

The EURAD Bureau, March 2023

.

Glossary

Terms

BWR	Boiling Water Reactor
CoP	Community of Practice
CSO	Civil Society Organisation
DBD	Deep Borehole Disposal
DGR	Deep Geological Repository
EJP	European Joint Programme
ERDO	Association for Multinational Radioactive Waste Solutions
EURADSCIENCE	A Network of Research Organisations for Radioactive Waste Management
GBS	Goals Breakdown Structure
IAEA	International Atomic Energy Agency
HHGW	High Heat Generating Wastes
HLW	High Level Waste
IGD-TP	Implementing Geological Disposal of radioactive waste Technology Platform
ILW	Intermediate Level Waste
KM	Knowledge Management
KMS	Knowledge Management System
LIMS	Large Inventory Member States
MOX	Mixed Oxide Fuel
MS	Member State
OECD NEA	Organisation for Economic Co-operation and Development - Nuclear Energy Agency
PMO	Project Management Office
PWR	Pressurised Water Reactor
RD&D	Research, Development and Demonstration
RE	Research Entity
RWM	Radioactive Waste Management
SIMS	Small Inventory Member States
SITEX	Sustainable Network for Independent Technical Expertise on Radioactive Waste Management

SNF	Spent Nuclear Fuel
SoK	State of Knowledge
SotA	State of the Art
SRA	Strategic Research and Knowledge Management Agenda
SS	Strategic Study
THMCB	Thermal, Hydro, Mechanical, Chemical, Biological
TRL	Technology Readiness Level
TSO	Technical Safety Organisation
WAC	Waste Acceptance Criteria
WMO	Waste Management Organisation
WP	Work Package

International or EC Project / Task Name Acronyms

ACED	Assessment of Chemical Evolution of ILW and HLW Disposal Cells (Work Package of EURAD, 2019-2024)
BEACON	Bentonite Mechanical Evolution (EC Project, 2017-2022)
BELBAR	Bentonite erosion: effects on the long term performance of the engineered barrier and radionuclide transport (EC Project, 2012-2016)
BENIPA	Bentonite barriers in integrated performance assessment (EC Project, 2000-2003)
BIOMOSA	Biosphere models for Safety Assessment of radioactive waste disposal based on the application of the Reference Biosphere Methodology (EC Project, 2001-2003)
BIOCLIM	Modelling sequential biosphere systems under climate change for radioactive waste disposal (EC Project, 2000-2003)
CARBOWASTE	Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste (EC Project, 2008-2013)
CAST	Carbon-14 Source Term (EC Project, 2013-18)
CEBAMA	Cement-based materials, properties, evolution, barrier functions (EC Project, 2015-2019)
CHANCE	Characterisation of conditioned nuclear waste for its safe disposal in Europe (EC Project 2017-2022)
CONCORD	Container Corrosion Under Disposal Conditions (Work Package of EURAD, 2019-2024)

CORI	Cement-Organics-Radionuclides-Interactions (Work Package of EURAD, 2019-2024)
CROCK	Crystalline Rock Retention Processes (EC Project, 2011-2013)
DECOVALEX	Development of Coupled Models and their Validation against Experiments
DONUT	Development and Improvement of Numerical Methods and Tools for Modelling Coupled Processes (Work Package of EURAD, 2019-2024)
DOPAS	Full scale Demonstration of Plugs and Seals (EC Project, 2012-2016)
ELSMOR	Towards European Licencing of Small Modular Reactors (EC Project, 2019-2023)
EURAD	The European Joint Programme on Radioactive Waste Management (EURAD). Also referred to as the 'Joint Programme' or EURAD-1 (EC Programme, 2019-2024).
FEBEX	Full-scale engineered barriers experiment in crystalline host rock (EC Project, 1996-1999)
FORGE	Fate of Repository Gases (EC Project, 2009-2013)
FUNMIG	Fundamental Processes of Radionuclide Migration (EC Project 2005-2008)
FUTURE	Fundamental Understanding of Radionuclide Retention (Work Package of EURAD, 2019-2024)
GAS	Mechanistic Understanding of Gas Transport in Clay Materials (Work Package of EURAD, 2019-2024)
HARPERS	Harmonised Practices, Regulations and Standards in Waste Management, and Decommissioning (EC Project, 2022-2025)
HITEC	Influence of Temperature on Clay-based Material Behaviour (Work Package of EURAD, 2019-2024)
JOPRAD	Towards a Joint Programming on Radioactive Waste Disposal (EC Project 2015-2019)
MAGIC	Chemo-Mechanical Aging of Cementitious Materials (Work Package of EURAD, 2019-2024)
MICADO	Model uncertainty for the mechanism of dissolution of spent fuel in a nuclear waste repository (EC Project, 2006-2009)
MODATS	Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure (Work Package of EURAD, 2019-2024)
MODERN2020	Development and Demonstration of monitoring strategies and technologies for geological disposal (EC Project, 2015-2019)
PREDIS	Pre-disposal management of Radioactive Waste (EC Project, 2020-2024)
RESEAL II	A large scale in situ demonstration test for repository sealing in an argillaceous host rock – phase II (EC Project, 2000-2007)

ROUTES	Waste Management Routes in Europe from Cradle to Grave (Work Package of EURAD, 2019-2024)
SFC	Spent Fuel Characterisation and Evolution Until Disposal (Work Package of EURAD, 2019-2024)
SoK	State of Knowledge (Work Package of EURAD, 2019-2024)
THERAMIN	Thermal treatment for radioactive waste minimisation and hazard reduction (EC project, 2017-2020)
UMAN	Understanding of Uncertainty, Risk and Safety (Work Package of EURAD, 2019-2024)

1. Introduction

1.1 Successful RD&D Collaboration across Europe

For more than 40 years, considerable scientific and technical knowledge has been acquired in Europe in the field of radioactive waste management (RWM), including for near-surface disposal (see for instance, the International Atomic Energy Agency (IAEA) Scientific and Technical Basis for Near Surface Disposal of Low and Intermediate Level Waste) and geological disposal (see for example, IAEA Scientific and Technical Basis for the Geological Disposal of Radioactive Waste [1]). This has supported numerous countries to progress towards the development of safe long term radioactive waste management programmes. For instance, licensing of geological disposal facilities for high activity wastes made important progresses these last years, e.g., Government approvals (for construction) for a final repository in both Finland and Sweden (and working towards preparation of a permit to operate), and submission of the application for authorisation of Cigéo in France. RD&D and Knowledge Management efforts in radioactive waste management, including disposal, will continue to be necessary in the future:

- To develop, maintain and consolidate scientific and technical knowledge throughout the stepwise development, operation and closure of disposal facilities, which will be spread over many decades and generations and make this knowledge available to end users;
- To ensure optimisation of waste management routes and of disposal solutions;
- To address evolving regulatory concerns;
- To make use of scientific developments in other areas;
- To bridge the risk of shortage of the skilled, multidisciplinary human resources needed to develop, assess, license and operate facilities for RWM; and
- To help in gaining and maintaining public confidence and mutual trust between RWM interested parties.

The European Commission (EC) has supported the acquisition of knowledge at the European level by supporting collaborative RD&D projects through the EURATOM programme on RWM. The EC has also enhanced coordination and networking activities by supporting the establishment of the Implementing Geological Disposal of radioactive waste Technology Platform (IGD-TP) - a network for European Waste Management Organisations (WMOs) which is now independently funded, and the SITEX Network for the regulatory expertise function (undertaken for instance by Technical Safety Organisations, or TSOs) providing support to regulatory authorities, which is also now independently funded. European Research Entities (REs) are also organised and have formed a corresponding network independently funded, called EURADSCIENCE. Together these three networks provide access to the main actors and categories of organisations supporting the implementation of radioactive waste management, leading to disposal, across Europe.

Today, the EC promotes a step-change in pan-European research cooperation between EU Member States' national programmes by promoting the setting-up of inclusive research and innovation joint programmes in Europe, attracting and pooling a critical mass of national resources on specific objectives and challenges. By step-change we mean a new era via a more effective and the efficient use of public RD&D funding in Europe, and a deepening of research-cooperation between Member States. The objective for the EC is therefore to promote and co-fund ambitious programmes rather than individual projects, bringing together those legal entities from EU Member-States or associated countries able to direct national funding and/or manage a national research and innovation programme.

The EC JOPRAD (Towards a Joint Programming on Radioactive Waste Disposal) project was launched in June 2015 with the objective to assess if the RWM community could be meaningfully integrated in a Joint Programme and to prepare the establishment of such a Joint Programme. By identifying those with key responsibility for directing RD&D in the field of RWM and engaging them in the process of developing a shared Vision and Strategic Research Agenda (among WMO, TSO and research entities), JOPRAD demonstrated the feasibility of creating such a Joint Programme in the field of RWM.

Based on this positive achievement, the EC confirmed its willingness to co-fund such a Joint Programme which has been in operation since 2019 – entitled the European Joint programme on Radioactive Waste Management, hereafter referred to as EURAD (or in the Tables in Section 5, EURAD-1).

1.2 Diversity of European national radioactive waste management programmes

National RWM programmes across Europe cover a broad spectrum of stages of development and level of advancement, particularly with respect to their plans and national policies towards implementing geological disposal. Programmes differ significantly depending on the national waste inventory, with some member states only responsible for relatively small volumes of medical and research reactor-derived wastes, compared to others that have comparatively large and /or complex waste inventories derived from large civil nuclear power (and fuel reprocessing) and defence nuclear programmes. Programmes also differ significantly in the way in which they are managed, particularly with respect to the national policy and socio-political landscape with respect to long-term management steps.

Under Article 14(2) of Council Directive 2011/70/Euratom [2] on the responsible and safe management of spent fuel and radioactive waste the Commission is required to submit to the European Parliament and Council, every three years, a progress report on the implementation of this Directive and an inventory of radioactive waste and spent fuel present in the Community's territory, with a view to future developments. Figure 1 below illustrates the different stages of implementation between 2040 and 2100 for different Member States [3].

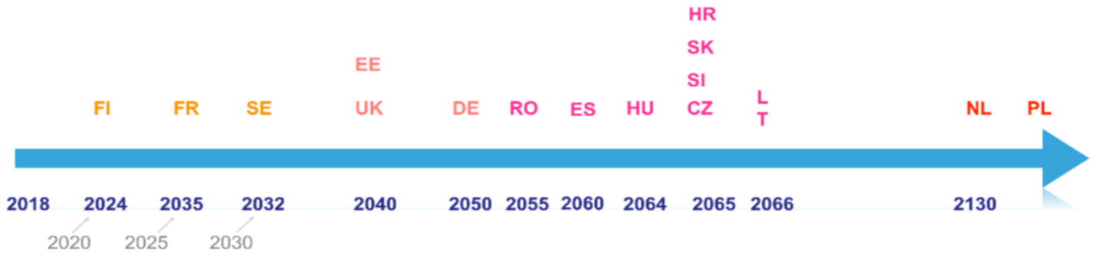

Figure 1: Planned start of operation of deep geological facilities (reproduced from [3]).

2. Background

2.1 EURAD Vision and Goals

The combined actions of the EC JOPRAD project (during 2016-2019) and the successful launch of EURAD in 2019 established a broad consensus and existing support for the EURAD Vision and SRA 2019 [4]. As part of the preparation of the EURAD SRA 2023, no significant change to either the Vision or EURAD Goals has been made [5]:

EURAD Vision

> A step change in European collaboration towards safe radioactive waste management (RWM), including disposal, through the development of a robust and sustained science, technology and knowledge management programme that supports timely implementation of RWM activities and serves to foster mutual understanding and trust between Joint Programme participants.

EURAD Goals

> EURAD will support the implementation of the Waste Directive in EU Member-States, taking into account the various stages of advancement of national programmes. Our Goals are to:

- Support Member-States in developing and implementing their national RD&D programmes for the safe long-term management of their full range of different types of radioactive waste through participation in the RWM Joint Programme;
- Develop and consolidate existing knowledge for the safe start of operation of the first geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste, and supporting optimisation linked with the stepwise implementation of geological disposal; and
- Enhance knowledge management and transfer between organisations, Member States and generations.

2.2 Contributors to the EURAD SRA 2023

Across Europe, the implementation and responsibility of RD&D and knowledge management programmes, in support of the safe management, including disposal, of radioactive waste, varies widely. At the highest level, most Member States have programme owners such as a ministry, national/regional authority or private organisation in charge of setting-up and thereafter the administration of a national programme. This is often followed by varying levels of 'programme managers', who have a formal mandate and delegated responsibility for technical research, development (and demonstration) activities, and knowledge management associated with the national programme.

Within EURAD there are three distinct categories of organisation, from across EU Member States, Switzerland, United Kingdom, and Ukraine, with scientific and technical responsibilities and a national mandate for research in RWM, and that are willing to share a Strategic Research and Knowledge Management Agenda (SRA) for European collaborative activities:

- **Waste Management Organisations** (WMOs) have ultimate responsibility for the implementation of geological disposal (which includes the management of a supporting RD&D programme), and for some the wider remit of RWM (including waste characterisation, treatment and packaging). WMOs from across Europe form a core part of EURAD and provide a driving force for what is needed for successful and practical implementation from an industrial perspective. WMOs have established a network and coordination framework for RD&D and knowledge management needs of the implementers of geological disposal at the European level via the Implementing Geological Disposal of radioactive waste Technology Platform (see, IGD-TP). There has been a continuous exchange of information and updates between IGD-TP and the Association for Multinational Radioactive Waste Solutions (ERDO) members, coordinated by COVRA. Small Inventory Member States (SIMS) of the WMO college that are neither member of the IGD-TP Executive Group nor of ERDO are included in decision processes.

- **Technical Safety Organisations** (TSOs) carrying out activities aimed at providing the technical and scientific basis for supporting the decisions made by a national regulatory body[1]. As safety cases for waste processing, storage and geological disposal develop, so too does the safety case review and independent scrutiny responsibility by regulatory organisations in the framework of the decision-making process. This requires specific skills from the regulatory expertise function undertaken by safety authorities, regulators, and their technical safety organisations (TSOs). Several TSOs, together with other organisations fulfilling a regulatory expertise function and Civil Society Organisations (CSOs) have established the SITEX Network to support independent technical expertise in the field of safety of geological disposal of radioactive waste; and

- **Nationally Funded Research Entities** (REs) work to different degrees on the challenges of RWM including disposal (and sometime in direct support to WMOs or TSOs), under the

[1] It is noted that the distinction between TSOs and REs in several Member States is a somewhat grey area as several Research Entities also fulfil (at least partially) an expertise function in their country and therefore also meet the conditions associated with the terms of a "TSO".

responsibility of Member States. This includes national research centres, some research organisations and some universities that could also be funded by other sources. The EURADSCIENCE network coordinates RE's who provide scientific insight and leading-edge research on basic components and generic processes in relation to the management of radioactive waste, and therefore represent a large proportion of the in-kind contributions to EURAD.

Each of the above three Actor groups has formed a College of EURAD, which together function to support the governance of EURAD, facilitated through nominated representatives that form the EURAD Bureau. The EURAD Bureau has been responsible for leading the update process of the EURAD SRA 2023, in close connection with the Colleges.

EURAD also includes observers and non-technical participants, who do not have a formal national mandate for research in RWM, but who are considered as key interest groups and may benefit from, or influence the direction of, specific activities undertaken. This includes:

- **Civil Society Experts**

  The socio-political dimension is a critical aspect to the successful implementation of safe RWM, including disposal. Within EURAD, a group of European CSOs who are involved in RWM activities at the EU or national level interact with the Joint Programme participants. These interactions are facilitated by Civil Society Experts. Throughout update of the EURAD SRA, CSO views have been considered within the TSO College Inputs (and Position Papers), and CSO experts have been invited to key Bureau SRA workshops and meetings to contribute to discussions and follow progress.

- **Waste Generators and the PREDIS Project**

  Waste Generators and those with a pre-disposal waste management remit are engaged via the EC PREDIS project. The PREDIS project targets the development and implementation of activities for pre-disposal management of radioactive waste streams other than nuclear fuel and high-level radioactive waste. Since its initiation in 2020, the PREDIS project has worked closely with EURAD and in 2022 a Memorandum of Understanding was established between PREDIS and EURAD to strengthen information sharing and cooperation. In 2021 the EC PREDIS project established its own baseline SRA [6] which has been further updated and published in March 2023 [7], acting as the key input to EURAD for identifying needs within the scope of predisposal activities that influence the wasteform for final disposal. Although not formally mandated as a College of EURAD, the PREDIS project has contributed to the update of the EURAD SRA though participation in SRA Bureau Meetings, by issuing a position paper and providing final editorial and review of the updated EURAD SRA.

- **International Organisations**

  It is recognised that the scientific basis and development of trust between stakeholders of RWM solutions, including geological disposal, is a global effort, and that new opportunities may emerge to link to worldwide RD&D and knowledge management efforts. EURAD has established close links with the IAEA and the Organisation for Economic Cooperation and Development – Nuclear Energy Agency (OECD NEA). Regular exchange supports the identification of synergies and to avoid duplication of effort and resource. Such co-operation continues, and extends to other organisations, to strategically direct and offer clear added value to EURAD objectives.

EURAD, through its delivery of the 2019-2024 Deployment Plan [8], has identified a number of tasks where outputs include recommendations for future work which have been considered by the EURAD Colleges for inclusion in the EURAD SRA 2023. The RD&D work packages of EURAD are yet to complete (see Section 3 for a summary of key achievements so far), therefore inputs listed below are limited to the strategic studies and KM work packages of EURAD who delivered recommendations in time for this SRA update:

- **ROUTES Work Package**

  The ROUTES work package of EURAD is a strategic study investigating waste management routes in Europe from cradle to grave. Outputs describe and compare the different approaches to characterisation, treatment and conditioning and to long-term waste management routes between MS (member states). One aim of this work package is to identify relevant R&D topics which could be collaboratively launched in the future.

- **UMAN Work Package**

  This UMAN (Understanding of Uncertainty, Risk and Safety) work package is dedicated to the management of uncertainties potentially relevant to the safety of different radioactive waste management stages and programmes. It includes various activities such as exchanges on views, practices and uncertainty management options and the review of existing strategies, approaches and tools. One aim of this work package is to network on emerging issues associated with uncertainty management that could be addressed in the future.

- **EURAD Knowledge Management Community of Practice**

  Those working across EURAD (and PREDIS) knowledge management tasks have formed a Community of Practice (CoP) to regularly exchange and network on all aspects of knowledge management within RWM. This CoP issued a number of recommendations for future work to the EURAD Bureau in November 2022, for inclusion in the EURAD SRA 2023.

2.3 Audience of the EURAD SRA 2023

This SRA is intended to be used as a stand-alone document informing the community at large (FISA/EURADWASTE) on issues and gaps in radioactive waste management, following a holistic approach on integrated management of radioactive wastes from cradle to grave. This view exemplifies the central role the EURAD community (at large, including PREDIS) and its 3 Colleges play in taking ownership of safe and optimised management of radioactive waste in current and future nuclear installations. It does not, by any means, intends to imply which funding schemes need to be coupled to implement actions following the publication of this SRA, nor does it imply that all the topics covered in the SRA should become an integral part of a follow-up programme to the current EURAD and PREDIS programmes/projects.

2.4 Scope and Themes of the SRA

The scope of the EURAD SRA 2023 remains unchanged and consistent with the EURAD SRA 2019, defined as: scientific and technical activities on radioactive waste management from cradle to grave (excluding dismantling and decommissioning of nuclear facilities which are covered by other EC Calls):

- Radioactive waste characterisation and processing (including treatment, conditioning and packaging);
- Interim storage and transport of radioactive waste; and
- Disposal solutions – mainly geological disposal of spent fuel, high-level waste (HLW) and long-lived intermediate level waste (ILW).

The EURAD SRA 2023 considers needs identified by the EURAD Colleges which are suitable for Joint Programming and that should be addressed or where results would be needed within the next 10 years.

The themes of the EURAD SRA 2023 remain unchanged and consistent with the EURAD SRA 2019, see for example Figure 1 below.

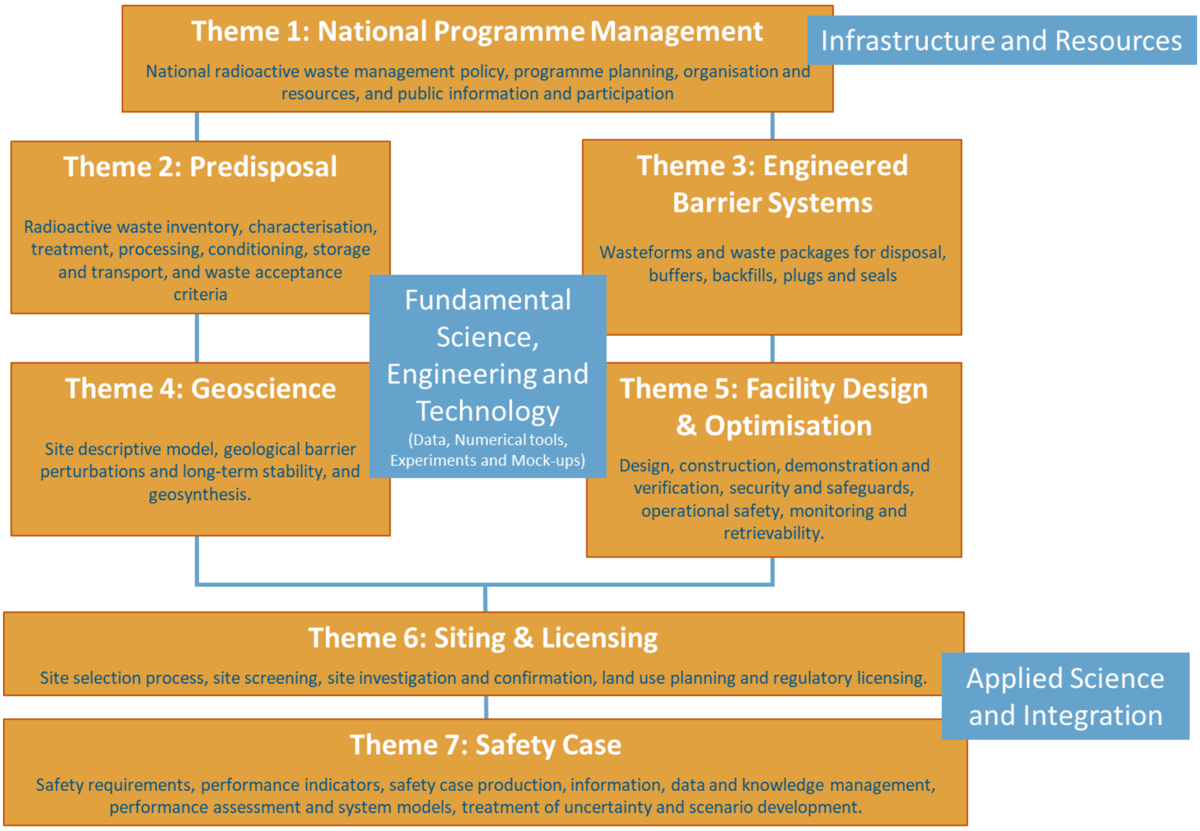

Figure 2: Themes of the EURAD SRA

A key update for the EURAD SRA 2023 has been to align the overall structure of the above seven themes with the extended goals breakdown structure (GBS) of the EURAD Roadmap [9]. The GBS comprises a hierarchy of generic radioactive waste management (RWM) programme goals and, in combination with the IAEA typical phases of implementing a deep geological repository programme, is the framework upon which the EURAD Roadmap is organised. Using a common structure has two purposes: (1) supports EURAD to signpost and structure the existing knowledge base in RWM (i.e., the Roadmap structure is currently used as the basis for developing and organising the EURAD Knowledge Management and Networking Programme [10] and for orienting the outputs of RD&D with respect to how results are used to support different goals of a RWM programme); and (2) for the identification of gaps in knowledge, i.e., we use it to structure the SRA.

2.5 Process to Update the SRA

The EURAD Bureau consulted with the EURAD Colleges during 2021 on the process to be used for development of the EURAD SRA 2023. An SRA update plan and process was formally issued as EURAD Deliverable D1.8 [11] in February 2022. The steps of the process are reproduced below in Figure 2.

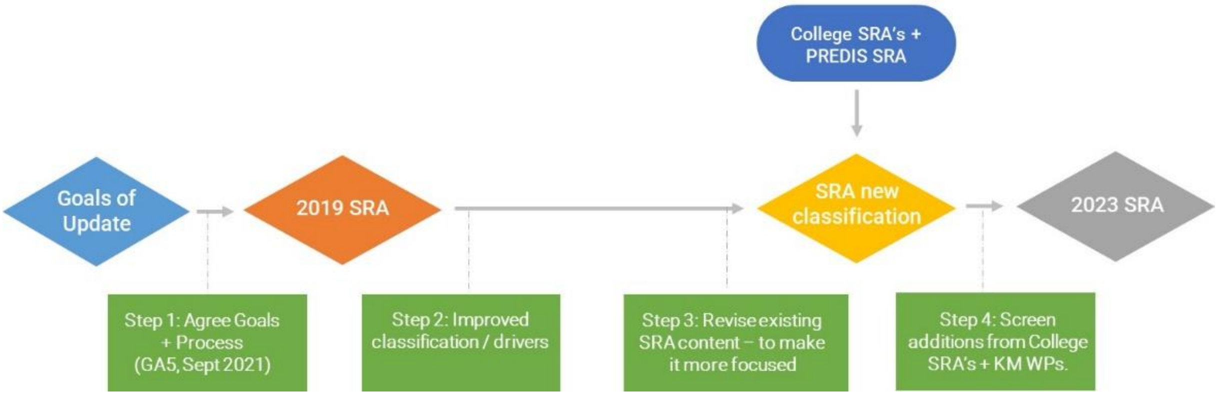

Figure 2: Steps of the SRA Update Process 2022/23

The four steps of the SRA update process have been:

Step 1: Agree the goals and the process (as described by D1.8 [11])

Step 2: Develop an improved characterisation scheme based on drivers for RD&D, Strategic Studies and KM. This helps to identify the 'why' for each need. This step has also included completed removal of a prioritisation scheme, i.e., the previous classification of High / Medium / Low is no longer used, resulting in an SRA that has no list of top priorities. How this will be managed in the future to develop prospective projects is explained in Section 6, and the characterisation by drivers is described more fully in Section 4.1, SRA Drivers.

Step 3: The contents of the EURAD SRA, 2019 will be re-organised into a format consistent with the EURAD Roadmap and each need will be better described to reflect its driver(s), i.e., why the topic should be studied. KM needs from the EURAD SRA will be merged or taken over by the KM priorities established by each of the EURAD KM WPs and will also adopt the approach of clearly defining the driver for the KM activity.

Step 4: Screen-in additions from the College SRAs and the PREDIS SRA. New and emerging needs have been captured and are characterised (but not prioritised) using the 'drivers' list used in Step 3.

In preparing and delivering the above SRA update process, the EURAD Bureau organised a total of 5 SRA Update Workshops (June 2021, November 2021, January 2022, May 2022 and October 2022). In addition to the workshops, formal position papers were developed by each EURAD College and PREDIS which acted at the main input to update of the SRA tables in Section 5.

College and PREDIS SRA's used in this update:

- TSO: SITEX contribution to the EC JOPRAD Programme Document (2019)
- WMO: IGD-TP Vision 2040 Strategic Research Agenda (2020)
- RE: EURADSCIENCE contribution to the EC JOPRAD Programme Document (2019)
- PREDIS: PREDIS Baseline SRA (2021)

Position Papers from the EURAD Colleges and the EC PREDIS project include:

- SITEX: SRA update process (2021) and SRA 2023 inputs (2022)
- IGD-TP: SRA update process (2021) and SRA 2023 inputs (2022)
- EURAD-Science: SRA update process (2021) and SRA 2023 inputs (2022)
- PREDIS: SRA 2023 inputs (2022)

Recommendations from the ROUTES WP considered in this update will be made available in the future within EURAD Deliverable D9.3 (March 2024). Recommendations from the UMAN WP will be made available in EURAD (March 2023).

2.5.1 Final consolidation and editing of the EURAD SRA 2023

Further to the SRA update process described above, to support the final step 4 on 'screening in additions' from the Colleges, several rounds of review and iteration have been necessary. This final consolidation ensured that needs communicated in the SRA are of a similar level of detail, so that they remain at a strategic level (i.e., to avoid overly specifying the details of potential work to allow for innovation and flexibility in future proposal development). Through iterations of final review and editorial coordinated by a small team of representatives of EURAD, the entries contained in the EURAD SRA 2023 have been screened through a process of rejecting items deemed out of scope, grouping, and removing overlaps or duplications. The Colleges did not organise an extensive exchange or consultation to support this final review and editorial process. Rather it is expected that the SRA remain sufficiently high level and such an exchange between College organisations and the wider RWM community, to build consensus on the exact details and specifics of future work (e.g., EURAD-2), will be managed through future project proposals. The SRA of EURAD will remain a tool to support the spirit of Joint Programming, and as such is considered a living document, with modifications and future changes possible.

3. What have we achieved so far (EURAD 2019-2023)

3.1 Evolving priorities and the evaluation of EURAD results

Since 2019, EURAD has implemented a range of work packages to support the objectives, priorities and activities of high common interest that were included in the EURAD SRA 2019. A summary of achievements, based on the work completed to-date is presented below, recognising that work packages will only fully complete in 2024. Once completed, it is the responsibility of the National Programmes to consider outputs and results with respect to their own needs (towards implementation). The use and interpretation of EURAD results in the context of the national radioactive waste management programme is an independent activity performed by Member States.

The priorities of RD&D and Knowledge Management for each member state depend notably upon the national radioactive waste inventory, host rock geology, national context and/or legislation, and the stage of the programme's lifecycle - with priorities changing as the programme progresses. For EURAD, our priorities have evolved since 2019, taking into account what we have learned and the results from our activities. From a practical perspective the EURAD community has shown that it is always possible to take scientific insight a step further, but the drivers behind that step evolve. For instance, in some areas it is definitely correct to state that knowledge is sufficiently advanced in order to proceed to the next step within a certain contextual framework (e.g., in the safe implementation of a specific national programme) but activities in such areas may still be of paramount importance to keep knowledge and expertise maintained, at least on a European scale. For this reason, we have chosen to avoid that statements are made which lead to the false conclusion that there is no longer any funding needed to support activities going beyond the current state of the art. Rather, our focus has been to reflect this evolution in the argumentation used to describe the drivers for each need in the EURAD SRA 2023. Finally, as part of the final consolidation exercise to prepare this SRA, some needs from the 2019 version have been removed, because they are not considered a strategic priority for Joint Programming.

A unique challenge to radioactive waste management is the timeframe: Throughout all phases of a programme, measures are to be taken over a period of at least 75 to 150 years. This not only raises the requirement of dedicated knowledge and research management but also the problem of the maintenance, availability and use of knowledge now and by future generations. This can only be done by ensuring that sufficient competence (people) and capability (infrastructure) remain available. The EURAD Bureau expects the EURAD Colleges to reflect further on how to organise the evaluation of results of EURAD work packages (for instance within a future EURAD Knowledge Management activity) and how to decide in a collegial manner how the drivers associated to the SRA needs evolve considering these results.

What have we achieved so far?

Having undertaken four years of RD&D, strategic studies and KM, with all work in support of implementing a national radioactive waste management programme, significant progress has been made. However, the work of EURAD is still in progress and will complete in May 2024. The sections below therefore present highlights and current achievements and are not the final EURAD results. The EURAD approach to performance management is that those responsible for performance are held to account using annual reports and reviews, all of which are openly accessible on the EURAD website. This is combined with a programme management office that aims to foster a collaborative culture and environment of constructive challenge via monthly work package leader meetings, monitoring of key performance indicators and continuous engagement with end user groups. A full list of EURAD work package deliverables and milestones achieved to-date can be accessed on the EURAD website (https://www.ejp-eurad.eu/).

3.2 Achievements of EURAD (2019-2023)

Programme Management

The Project Management Office (PMO) work package has coordinated the development of the EURAD Roadmap. It shows the role and relevance of the different themes for waste management and disposal programmes at different stages of implementation. The EURAD Roadmap is a representation of a generic radioactive waste management programme that enables users and programmes to 'click-in', and access existing knowledge and active work or future plans in EURAD and elsewhere. The content (for example, seven theme overview documents and tens of domain insight documents are either complete or will be available by the end of EURAD). The Roadmap content is focused on what knowledge, and competencies (including infrastructure) is considered most critical for implementation of RWM, aligned to the EURAD Vision.

The State of Knowledge (SoK) work package aims to preserve and make knowledge created in the field of radioactive waste management (RWM) research accessible to any interested end-users. The SoK is defined as the science and technology behind RWM in a specific domain and it is made accessible through a hierarchy of KM documents, structured according to the goals breakdown structure of the EURAD Roadmap. These documents capture the experts' view on the most relevant aspects in each topic allowing end users to access knowledge at different levels of detail. Furthermore, the SoK work package is developing a Wiki and drafting a sustainable Knowledge Management System (KMS).

Key achievements and results delivered by the SoK work package include the production of a SoK document demonstration case on Domain 3.1.1 - Spent Nuclear Fuel by Kastriot Spahiu (Nov. 2021) followed by an information session (Jan. 2023). Furthermore, several Domain Insight documents have been finalised and (more than half are in the production stage). Based on the experience, procedures for developing these documents have been established. Additionally, the specifications of a online platform Knowledge Management System have been developed based on the screening and review of existing KM approaches and tools.

The training and mobility work package of EURAD has established the 'School of Radioactive Waste Management (RWM)'. The School of RWM acts as the executive body for all training and mobility activities that are organised within EURAD. It responds to the needs of European RWM organisations concerning training and mobility. The school focusses on four main pillars: (i) courses and webinars; (ii) mobility actions; (iii) panoramic overview of all aspects related to RWM (it does this through all of its activities); (iv) support the EURAD PhD community. By linking its activities to the EURAD Roadmap, the School of RWM contributes directly to the strategic knowledge management objectives of EURAD, namely: (i) preservation of generated knowledge (in- and outside of EURAD), (ii) transfer of knowledge towards Member States and between generations and (iii) dissemination of knowledge (by organising training courses based on identified training needs within RWM). Through the School, 7 bespoke training courses have been delivered and 31 mobility actions supported. A guidance document on training organisation and a list of existing training courses in RWM (available external to EURAD) has also been compiled. Monthly lunch and learn sessions are organised, providing a short, informal, one-hour sessions that is aimed at everyone in EURAD to disseminate the progress of work being done in EURAD, and more generally to share industry-wide good practice, and invited talks from professionals.

Additionally, the EURAD guidance work package is developing a comprehensive suite of instructional guidance documents that can be used by Member-States with RWM programmes that are at an early stage of development with respect to their national RWM programme. A key achievement has been to complete a comprehensive mapping of existing guidance and guide-like documents available internationally in relation to implementing geological disposal of higher activity radioactive waste. A cost guidance has recently been developed and publicised through lunch and learn webinars, and now planning has started to initiate guidance development on requirements management.

Predisposal

The ROUTES work package of EURAD is a strategic study to compare the different approaches to characterisation, treatment and conditioning and to the long-term waste management routes between MS (member states). The interested organisations are from different countries, with programmes at different stages of development, with different amounts and types of radioactive waste to manage. The work package has identified the 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. A major focus has also been on exchanging and networking on approaches for challenging wastes. Since this work package has a goal to identify R&D needs of joint interest, views and inputs from the ROUTES network have been used to deliver the EURAD SRA 2023.

The SFC (Spent Fuel Characterisation and evolution until disposal) work package has developed and documented an experimentally verified procedure to accurately determine the source term of irradiated spent fuels. It is also developing characterisation techniques that will allow improved understanding of the physiochemical evolution of irradiated spent fuels (pellets and cladding) under normal and credible accident scenarios following reactor discharge (i.e., during interim storage (wet and dry), transport to and emplacement in a GDF). Recent work package highlights include the selection of two SNF dry casks (PWR and BWR) for criticality analysis during normal, abnormal, and accidental conditions. These analyses have been carried out with spent and fresh fuel for a series of selected scenarios. Another highlight has been the completion of three-point bending tests with a newly developed device performed with fresh and pre-hydrided samples, with and without ceramic inserts, simulating fuel pellets at room temperature, 135 and 300 °C. This work package has also prepared a comprehensive State of the Art (SotA) report detailing an overview of the state of knowledge in the field of spent nuclear fuel characterisation and assessment during the pre-disposal phase.

Engineered Barrier Systems

The ConCorD (Container Corrosion under Disposal Conditions) work package of EURAD aims to explore the potential of novel and / or advanced container materials and processes for optimisation of container performance within the engineered barrier system. This includes increasing the understanding of complex/coupled interfacial processes influencing container performance under repository relevant conditions, with a focus on irradiation-accelerated corrosion, microbial activity and degradation during nearfield transients. The work will demonstrate the obtained mechanistic process understanding and develop predictive models, which will incorporate system variability and will lead to more focused performance assessments addressing identified safety needs, as identified in Roadmap domain 3.2.1 HLW and Spent Fuel Containers. Key achievements obtained so far include the production of a SotA report synthesising the literature on relevant subjects. The SotA has been well received by the wider container development and corrosion community and is currently being translated to Japanese. On the experimental front, significant progress has been made in the optimisation of sealing materials and processes for ceramic canisters. Even though testing needs to be completed, the efficiency of the sealing process has been improved.

The GAS (Mechanistic Understanding of Gas Transport in Clay Materials) work package of EURAD aims to increase the understanding and predictability of the processes that control gas transport through clayey host rocks and clayey engineered barriers of geological disposal systems and the consequences of these processes on the long-term properties of those materials. It also aims to support the stepwise integration of the knowledge on gas transport and its effects in conceptualisations of the functioning of a disposal system in support of the safety case. This work is linked to Roadmap domain 4.2.1 on perturbations, which includes consideration of gas perturbations and its impact on longer disposal system evolution. In the GAS WP, the refinement of the mechanical understanding was supported by new data and critical review and refining of concepts for gas transport through clays. Outputs include process level models that better account for the couplings with the mechanical behaviour of clays and the impact of the passage of gas on their properties. Experimental work that was carried out has allowed to refine, for each identified gas transport regime, the range of conditions under which that regime is possible in clay materials representative of a host formation or clayey EBS components. This WP also provided practical examples of how knowledge gained from laboratory and in situ experiments can be integrated into the conceptualisation of gas transport through clayey components of a disposal system and how gas can affect the performance of the system. The GAS WP has presented in a transparent way what is known and what are the residual uncertainties to manage throughout (i) the development of phenomenological descriptions of gas transport and of its likely consequences at the relevant scale and (ii) the testing of different approaches to represent the effects of gas at the repository scale and bounding its consequences in terms of impact on the functioning of a geological disposal system.

The MAGIC (Chemo-Mechanical Aging of Cementitious Materials) work package of EURAD aims to understand the chemo-mechanical aging of cementitious structures exposed to coupled disturbances (chemical, microbiological and mechanical) representative of those encountered in the geological disposal during its complete lifetime. Through a multi-scale approach, it considers both numerical and experimental approaches. Key achievements and results delivered by MAGIC include experiments to underpin the detailed description of the reactive processes (from the microscopic to the macroscopic scale) to which the cementitious materials are exposed in the context of radioactive waste disposal in a clayey environment: a) during the operational phase (mainly atmospheric carbonation and reinforcement corrosion); b) long term (multi-ionic disturbances coming from the host rock at the interface or at the free surface), with the consequences in terms of mechanical damage/reinforcement (Young Modulus, compressive strength). Modelling is also pursued for a base case of a multi-metric cement disposal cell, from the operating period to the long term, taking into account all the chemical processes encountered in a clayey environment and their consequences on behaviour mechanics of the structure, as well as the natural loading of the host rock. This modelling integrates all the chemical parameters identified as first-order in experimental and numerical work at a smaller scale. This is an integrative work taking into account all the key contributions of the work package. A key highlight is also that for the first time at the European level, a series of comparative studies is initiated on the chemo-mechanical aging of cementitious materials exposed or not to microbial disturbances. It makes it possible to identify whether biological activity plays a role or not in the degradation of structures.

The ACED (Assessment of Chemical Evolution of ILW and HLW Disposal Cells) work package aims to improve the methodology to integrate knowledge on the geochemical processes in and between the materials in a disposal cell for ILW and HLW waste in order to understand and assess the long-term evolution of such complex systems. A multi-process and multi-scale modelling framework is under development to enable the assessment of the chemical evolution at various materials interfaces and thermal, hydraulic and/or chemical gradients from the microscale to the disposal cell scale (ILW, HLW) considering the near field environment and the host rock for larger temporal scales. Starting from small-scale process understanding, it seeks to which detail geochemical processes need to be included for representative assessments of the chemical evolution in view of the needs in repository design and safety assessment. Major recent achievements have been the completion of the experimental characterisation programme on selected waste packages and the integration of experimental and modelling studies.

The CORI (Cement-Organics-Radionuclides-Interactions) work package performs research to improve the knowledge on the organic release issues which can accelerate the radionuclide migration in the context of the post closure phase of geological repositories for ILW and LLW/VLLW including surface/shallow disposal. CORI research addresses topics in the context of cement-organics-radionuclides-interactions. The potential effect of organic molecules is related to the formation of complexes in solution with some radionuclides of interest (actinides + lanthanides) which can increase radionuclide solubility and decrease radionuclide sorption. Organic substances require special attention since a significant quantity exists in the waste and in the cementitious materials, with a large degree of chemical diversity. The three R&D Tasks in CORI to be shortly introduced are: (i) Organic Degradation., (ii) Organic-Cement-Interactions and (iii) Radionuclide-Organic-Cement-Interactions. Radionuclide migration processes are studied in the ternary system. The role of organic molecules on the transfer properties of radionuclides are investigated through sorption and transport experiments. Selected radionuclides cover a range of chemical characteristics and redox states relevant for conditions in L/ILW disposal. Technical progress in CORI has been achieved on several levels, often using synergies between different groups and countries. CORI was presented at EURADWASTE 2022 in order to put this activity into a broader EURAD context. CORI further has prepared a State-of-the-art report on cement-organic- radionuclide- interactions, summarising basic information relevant in this specific context. Interactions with the ICS group and UMAN establish a new dimension of information exchange and networking in EURAD beyond discussing the genuinely technical work.

Geoscience

The DONUT (Development and Improvement of Numerical Methods and Tools for Modelling Coupled Processes) work package of EURAD aims to improve and develop methods or numerical tools in order to go a step further in the development of relevant, performance and cutting-edge numerical methods that can easily be implemented in existing or new tools, in order to carry out high-performance computing to facilitate the study of highly coupled processes in large systems. These methods and their implementation in tools have been mainly applied to reactive transport, 2-phase flow, and THM modelling in porous and fractured media. Numerical scale transition schemes for coupled processes (meso1 to macro scale) have been further investigated, supporting the study of specific multi-scale couplings such as chemo-mechanics. Also, innovative numerical methods to carry out uncertainty and sensitivity analyses for coupled processes have been explored. Key achievements and results delivered by DONUT include production of a SotA which brings together a first of its kind synthesis of the codes, methods and tools that are being developed further within EURAD. It has acted as a central reference for the different modelling teams and through its production acted as a key catalyst for establishment of a new Community of Practice for Digital Twins. This has led to further organised dedicated community webinars and position papers to strategise the future direction of Digital Twins, with DONUT contributing on how to integrate multiscale representation.

The FUTURE (Fundamental Understanding of Radionuclide Retention) work package aims at realising a step change in quantitative mechanistic understanding of radionuclide retention in the repository barrier system, the key mission of any repository for radioactive waste. In consequence, the aim of this work package concerns the identification of constraints and the increase in predictability of radionuclide migration properties in "real" clay and crystalline rocks, quantifying the influence of key parameters of the heterogeneous rock/water system. Properties investigated include rock structure, redox interfaces, water saturation, reversibility etc., with the goal to develop multicomponent mechanistic sorption models, fracture and/or pore scale simulations of radionuclides transport. Highlights include results from experimental activities on the sorption and transport of radionuclides that are providing increasing evidence that data on dispersed systems can be transferred to compacted state for most of the elements studied in the project. Reactive transport experiments and simulation in crystalline rocks have also proven successful, providing a consistent model for Ra retention and mobility. A key success of this work package has been the increasing number of results derived from the experimental activities which have been shared with and used by the modelling teams in the DONUT work package.

The HITEC (Influence of Temperature on Clay-based Material Behaviour) work package aims to develop and document improved THM understanding of clay-based materials (host rock and buffer) exposed to elevated temperatures (>100°C) for extended durations. The work package's rationale is to evaluate whether elevated temperature limits (of 100-150°C) are feasible and safe for a variety of geological disposal concepts for high heat generating wastes (HHGW). Work has studied clay host rock formations (<120°C) and investigates the possible extent of elevated temperature damage in the near or far field (e.g., from over pressurisation) and also the consequences of any such damage. A key highlight has been the publication of the preliminary SotA which presents the main characteristics of the national geological disposal concepts of the organisations involved in EURAD and particularly of their thermal limits.

Facility Design and Implementation

The MODATS (Monitoring Equipment and Data Treatment for Safe Repository Operation and Staged Closure) work package aims to consolidate the implementation strategy for monitoring systems by developing methods through which confidence can be demonstrated in the data acquired and benefits derived for repository implementation. Repository monitoring also presents challenges related to evaluation of multi-modal data, i.e., data that is measured by different sensors, resulting in a range of independent parameters, at different locations and at varying spatial and temporal sampling. The work package is undertaking R&D into data acquisition, data management and presentation, and applying results and derived data to support system understanding. Key achievements to-date has been the finalisation of the SotA report.

Safety Case

In radioactive waste management (RWM) programmes, decisions are made in the presence of a wide variety of irreducible and reducible uncertainties. But how does each category of actors involved in the programme (WMOs, TSOs, REs) assess the significance for safety of uncertainties and what is the approach used in uncertainty management? And how does Civil Society perceive the problem of uncertainty in the decision-making process? The UMAN (Understanding of Uncertainty, Risk and Safety) work package of EURAD addressed these questions with the threefold aim of reaching a common (or at least a mutual) understanding of the uncertainty management and how it relates to risk and/or safety, of assessing the contribution of the past and ongoing research to uncertainty management and of identifying associated remaining and emerging issues and needs. The views of the three categories of actors were integrated into a comprehensive multi-layer uncertainty classification matrix and a general uncertainty management strategy based on an iterative, stepwise and flexible approach. Uncertainties associated with waste inventory, spent nuclear fuel, site and geosphere, and human aspects of high importance for disposal safety were identified and discussed at expert level (in dedicated UMAN workshops) to collect specific options for their management.

The nature of the RW disposal programme and the stage in its implementation, as well as the responsibilities and role of each actor in the programme influence the degree of significance for safety and their preferences in approaching uncertainty management. R&D, dialogue with all stakeholders, progress in site characterisation and an iterative safety assessment process are however the most used actions to reduce and avoid uncertainties or mitigate their impact.

Feedback on the actors' views, collected during the UMAN seminars from a broader audience, highlighted a particular interest of Civil Society in the uncertainties associated with the intergenerational governance, which is seen important to the success of the RWM programme and disposal safety.

4. Orientation of the EURAD SRA 2023

The EURAD SRA 2023 has been updated under the auspices of EURAD (2019-2024) and is one of the founding documents of EURAD, complementing the EURAD Vision, Implementation Plan and Governance Scheme. The updated EURAD SRA 2023 remains in line with the EURAD Vision, with scope focused on RD&D and knowledge management needs that support Member States to progress with timely implementation of their national radioactive waste management plans – including predisposal and disposal activities. A large focus within the EURAD SRA is on RD&D, i.e., scientific, and technological advancements. This is fully linked to activities that are more of a knowledge management or networking nature, particularly to maintain and share know-how between programmes at different levels of advancement.

The EURAD SRA 2023 has been developed with a 10 years forward horizon, building upon and complementing the extensive knowledge base that exists in radioactive waste management which has been developed over the past decades by the national programmes. In this respect, the EURAD SRA 2023 should be viewed as one of many programmes of science and technology that pursues the advancement and timely implementation of geological disposal. Most WMOs have extensive RD&D programmes and some joint challenges are addressed within international cooperation activities external to European-funded projects. Therefore, in on our efforts to identify needs of common interest that could be addressed through cooperation at the European level, we have engaged with representatives of the EURAD Colleges (and therefore the respective national programmes), and IAEA and OECD NEA to ensure that our SRA complements activities that are continuing elsewhere.

4.1 SRA Drivers

The following list of drivers was established between the EURAD Colleges and PREDIS for characterising all needs in the EURAD SRA 2023.

Table 1: EURAD SRA 2023 Drivers

Driver Shorthand	Driver Explanation
Implementation Safety	Contributing to the safe construction, operation and closure of deep geological repositories (and other disposal facilities), ensuring long-term safety.
Tailored Solutions	Supporting the development of tailored solutions for the management of various radioactive waste types in Europe: • Working together on scientific, technical, managerial, societal and regulatory issues of common interest and considering the full range of potential disposal solutions and waste groups accounting for IAEA's graded approach and taking economic aspects into consideration. • Increasing robustness of approaches by addressing cross-correlations, path dependencies and potential pitfalls in the RWM strategy.
Scientific Insight	Advancing state of the art science in waste management and disposal throughout the waste management chain:

	• Exploratory research in areas with significant uncertainty or in areas with high potential to improve knowledge.
Innovation for Optimisation	Supporting RWM innovation for optimisation: • Continuously managing uncertainty, improving robustness, reducing complexity, costs and other resources and optimising RWM routes and advancing technology and solutions to meet the needs of Member States.
Societal Engagement	Helping to engage with and maintain mutual trust with stakeholders, and awareness in RWM: • Fostering transparency and fruitful interactions with Civil Society along the different phases of a RWM programme.
Knowledge Management	Enhancing knowledge management and transfer between organisations, Member States and generations: • Capturing, maintaining, and efficiently developing skills, knowledge and infrastructure, in view of the long lead-times and the intergenerational dimension associated to RWM.

4.2 Links to the EURAD Roadmap

The EURAD Roadmap signposts to latest state of knowledge, guidance, training, and existing networks for many of the 80+ domains of the EURAD goals breakdown structure. Where available, this context provides further background for each of the needs identified in the EURAD SRA 2023.

4.1 Format of the SRA Tables

The SRA tables in Section 5 constitute the core of the EURAD SRA 2023. Structured according to the goals breakdown structure of the EURAD Roadmap, each need is characterised by:

- **Domain identifier**: A link to the corresponding Roadmap domain(s) – a 3-point numbering system and domain title is illustrated, together with links to any available Roadmap domain insight documents which will elaborate further available context and definition of existing state of knowledge and remaining uncertainties.

  For example, Domain 3.1.4 (unique number), Other wasteforms (domain title)

- **Short Title:** This is a definition of the RD&D, strategic study or knowledge management need using a short objective or title.

  For example, Improved understanding of radionuclide release from existing and future wasteforms other than Spent Fuel and HLW glass.

- **Drivers:** One or more drivers from the common list of SRA drivers (illustrated in Table 1) are used to characterise the 'why' for each need. This provides a clear link from the knowledge gap to the strategic need for progressing the work (and implicitly provides guidance on the primary customers and end users who should direct the specification of any work progressed and evaluate results once work is completed). The characterisation of needs using drivers is not a priority measure, e.g., those needs which have a higher number of drivers does not infer a higher priority. There is no evaluation of priority made in this SRA across the needs.

  For example, Drivers: Implementation Safety & Scientific Insight, Argumentation: Development of the post-closure safety case could be improved by better underpinned parameterisation of the models of radionuclide release, focusing on specific radionuclides and their chemical speciation with high safety significance (for example, carbon-14 from irradiated graphite) and by considering a wider range of waste characteristics and irradiation histories than previously studied.

- **Expected outcomes and impact**: This provides guidance on expectations for the outputs of any work progressed.

  For example, Improved understanding of the radionuclide release mechanisms and associated kinetics for metallic wastes, high organic content wastes, graphite, bitumen and cementitious wasteforms.

- **Cooperation and relevant past projects:** This signposts to relevant networks, recent projects and/or related work that is ongoing or in the pipeline outside of EURAD (e.g., IAEA, NEA or Projects within national programmes.

  For example, EC CAST project, EC CHANCE project, HTR-N, Carbowaste

The tables in Section 5.2 - 5.8 are majorly needs that would be addressed through RD&D actions. Needs primarily of a strategic study, KM and/or interactions with civil society nature are also included.

For many of the KM items (especially on networking or sharing experiences on methodologies that exist) the effort required could be significantly lower compared to other items on RD&D and strategic studies.

Any new items that have been added as part of this update are prefixed with a NEW indicator.

5. The EURAD SRA 2023

5.1 Summary of the EURAD SRA 2023

Each of the EURAD College and PREDIS position papers (see for example, links in Section 2.4) from October 2022 provided constructive and directive inputs that have been used to update the tables of needs of common interest in Section 5. Application of drivers to characterise all needs to make the SRA more useful for future definition of work packages has been the main activity during the preparation of the EURAD SRA 2023. Position papers additionally highlighted organisational perspectives on new SRA needs and/or reinforced the continued importance for existing domains where challenges remain. The broad activities mentioned below reflect those strategic aspects that are considered challenging or that present major opportunities that can be realised in the next ten years. Text in bold indicates key aspects that the Colleges wish to emphasise.

Integrated waste management[2] to deliver the benefits of joint programming, more proportionate risk-informed approaches, better coordination, optimisation of waste/material handling practices and reduced costs across the full waste lifecycle remains a critical enabler for successful programme management regardless of the stage of implementation. The importance of this coordination within the lifecycle backend is reinforced through the strong cooperation between EURAD and the PREDIS communities and agreement on areas of focus where optimisation of waste management between predisposal and disposal activities require continued effort. Emphasis continues on application of the **waste hierarchy** alongside improvements and deepening of application of **sustainability goals** in strategic waste management decision-making, including application of **circular economy** principles.

Given that many predisposal facilities are in operation across Europe, and the maturity of existing technology routes is typically high, RD&D for predisposal is primarily on items that will lead to a major technology change and/or **step changes in technical readiness level (TRL)**. Considering the multi-generational character of some of these sites (e.g., extended long term interim storage of spent fuels and other long-lived radioactive waste), joint needs for KM continue to be important in some areas. Several areas are reinforced by PREDIS including continuing to improve understanding of **problematic wastes and novel solutions for small inventories** (i.e., research reactor fuels), particularly mobile

[2] Integrated Waste Management in the nuclear sector typically refers to taking a holistic view of waste management routes and strategic options across the full lifecycle of waste management.

treatment facilities and new approaches for waste characterisation, treatment and processing, including options for handling mixed wastes and implementing more **environmentally friendly materials**. Continued efforts are required to share good practice, develop and maintain guidance and improve information management for **waste characterisation methods** and the benchmarking of available decontamination technologies. No ranking of domains is included in the EURAD SRA, but inputs from the PREDIS project highlighted the following as highest importance: Waste characterisation (with a focus on non-destructive techniques); Waste Acceptance Criteria (WAC); Conditioning and Packaging; and Separation and Treatment processing.

An emerging need that spans across predisposal and disposal domains is the challenge and opportunities of a **more digital future**. This impacts the capacity of different tools and enables more advanced automatisation to proceed. The newly developed tools can be used in many ways for planning, design, implementation, evaluation and visualisation and documentation in the different steps of a waste management programme. It is also considered that digitisation can run horizontally through the programme (e.g., exchange on and shared central tools or **large-scale digital representation** that can **integrate the results** from different work packages, and in data management (and data harmonisation) to allow artificial intelligence and machine learning). This may raise challenges but could also provide new opportunities for KM and for exchange between early and advanced programmes. The common European view is important. The different tools are developed within PREDIS and EURAD and in other industries around the world. It requires effort at the European level to have the backend of the nuclear industry as a forerunner in this field.

RD&D continues on spent nuclear fuel, including the **effect of long-term interim storage** and **damaged fuel** on interim storage safety, transportability to a repository site and performance under repository conditions, **including criticality issues**, and the behaviour and insights into more **special fuels (Mixed oxide fuel (MOX), doped fuels, new fuel types, accident tolerant fuels**) throughout the whole back end. Characterisation of all waste streams with a focus on safety relevant radionuclides and studying the long-term behaviour of waste forms (HLW, LILW) under repository conditions also remains, to better understand key controls and limit uncertainties on the safety functions that could be associated with these waste forms.

For domains primarily concerned with implementation of DGRs, but also in the further exploitation of (near) surface facilities, emphasis is reinforced on the continued **optimisation of engineered barrier material and design concepts**, particularly to enable industrialisation of these facilities. The term optimisation in the context of implementing geological disposal facilities has widened from focussing initially on post-closure nuclear safety to many other aspects (e.g., design, engineering, cost, environment, acceptance). Optimisation to implement geological disposal has thus become a multi-stakeholder and multi-objective challenge. The waste management concepts, and designs (for different types of waste categories) require huge amounts of manmade and natural materials and related logistics and installation aspects. The performance of the materials is the most important aspect and is handled generally in the safety case. Since disposal projects typically have very long timescales, the needs for updates in materials (innovative materials that become available and could decrease some uncertainties or current materials that will have limited availability in the future) are required in several steps in order to guarantee and/or increase the performance. However, there might be other drivers. For example, the **sustainability and awareness of energy sources**, and **availability of raw materials** is more critical in the current world situation, thus these topics are included in the SRA. New environmentally friendly materials require similar types of performance studies and underpinning of safety arguments, comparable to materials historically considered in the safety cases for DGRs internationally. Also, costs and uncertainty management associated with materials for engineered barriers could drive optimisation.

Small Modular Reactors (SMRs) and work to evaluate **new types of reactor waste** is reinforced. The plans in Europe are that the first SMR facilities would be in operation in next decade (2030-2040) and 4th Generation reactors a decade later. This sets a need to holistically investigate the aspects for SMR and new type of reactors waste management, from predisposal through disposal and for both LILW and HLW.

The importance of the **integration of technical and social aspects** within Joint Programming remains visible and the TSO College of EURAD, via the SITEX Network, continues to integrate technical and social aspects in its identification of needs for consideration in the EURAD SRA 2023. This includes the identification of the needs in social and citizen sciences associated with radioactive waste management and disposal and reinforcement that such items cannot be investigated separately from the technical aspects.

Recognising the **long timescales** involved and the different pace in various European countries for implementing radioactive waste management, **knowledge management** remains critical and is considered a key enabler for supporting all national programmes. Data gathered within EURAD as well as in previous EC programmes on radioactive waste management shall be accessible for the community, now and in the future, making sure these can be used in a **quality assured** productive way. This will not be a simple exercise and requires more efforts. Challenges remain on **accessibility to codified knowledge and information**. A key message raised in this update is that KM in EURAD should **focus on competence development**, making KM a more active state-of-mind (compared to a more passive "library collection of knowledge") and improve understanding of relevant knowledge within a future EURAD that could lead the way to a real step-change for the community in this field.

Following on from the above messages related to KM, further reflections are shared relating to strategic directions a future EURAD can take in order to sustainably support the whole community and the different Member States (and their associated National Programmes) in driving innovation in research and technology, training new experts and ensuring transfer of knowledge. One aspiration is that EURAD could evolve to be the go-to place to structure and organise radioactive waste management **competence, know-how and capabilities** on a European scale, which includes the school for radioactive waste management as a European knowledge management (KM) platform and for training[3] **new young experts**, a network of **state-of-the-art research infrastructures** (hot labs, URLs, etc.), acting as a think tank and writing position papers on important/emerging topics, with a high visibility (nationally and internationally).

Finally, across all the work undertaken and pursed in the future it is reinforced that **scientific excellence,** not only excellence in scientific research, but also in all the activities implemented through Joint Programming, will support the credibility of results and contribute to the advancement of radioactive waste management in Europe.

This summary of the EURAD SRA 2023 represents only key messages that the EURAD Colleges wish to highlight. It is not exhaustive of all topics and does not represent a list of future projects The following tables within Section 5 represent the core of the EURAD SRA 2023, which includes many items that are not highlighted in this summary.

[3] Scope within EURAD is limited to training and mobility, therefore education is excluded.

5.2 SRA Theme 1: National Programme Management

[Roadmap Theme Overview 1](#) provides background context and summarises existing knowledge in relation to the goal of implementing a national programme for the management of spent fuel and radioactive waste, covering all types of spent fuel and radioactive waste under its jurisdiction and all stages of spent fuel and radioactive waste management from generation to disposal. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 1.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
1.1.1 National RWM Policy	**NEW: Support national programmes to maintain a national plan for radioactive waste management, including a nuclear fuel cycle strategy (e.g., open or closed cycle) for those countries with, or intending to use, nuclear power** Expected outcomes and impact: Guidance on methods and processes to setup and advance/progress a RWM programme for early-stage programmes. Aspects to take into consideration in RWM programmes under political and environmental unstable conditions. Pathways for implementation of shared RWM disposals. Cooperation and relevant past projects: ERDO network, IAEA guidance	**KM, Innovation for Optimisation, Societal Engagement** Several (strategic) studies and/or guidance could be developed to ensure that Member States in different socio-economic situations and/or political context can advance with the implementation of their programmes.
1.1.3 Public information and participation	**NEW: Ensure that public information on radioactive waste and spent fuel and a process for public participation are available** Expected outcomes and impact: Build upon the developed methods of fruitful interaction from EURAD-1 between the Colleges and CS experts to establish dialogues in several WPs in the future Joint Partnership. This dialogue between Colleges and CS experts will enable feedback of the CS experts on research questions, interim and final results and will help the Colleges to understand how their research is perceived by the public and how communication about the research could be improved. A guideline for RWM research and how to interact with CS actors in the field of research will be compiled based on interaction results in different WPs. Cooperation and relevant past projects: IAEA guidance and networks on stakeholder engagement, EURAD-1	**Societal Engagement** This topic will help to establish structured interaction between researchers and CS actors in the frame of research programmes and projects. Inclusion of CS in research will help foster mutual understanding also in other steps of RWM.
1.1.4 Safety, security and use of resources	**NEW: Networking on approaches and requirements for satisfying sustainability objectives** Expected outcomes and impact: Exchange of approaches and concepts regarding sustainability in the context of nuclear waste disposal. Shared experience and networking on the approach to sustainability, in connection with the United Nations sustainable development goals. Determination of the relevance of different dimensions of sustainability, e.g. A) environmental (e.g., impact on nature, especially on soil and water; high consumption of energy and other	**KM, Innovation for Optimisation, Societal Engagement** Networking on approaches and requirements for satisfying sustainability objectives. Exchange of approaches and concepts regarding sustainability in the context of nuclear waste disposal. Shared experience and networking on the approach to and implementation of sustainability, in connection with the United

	resources; GHG emissions), B) economic (e.g. high costs for materials, processes and technologies) and C) social (e.g. social acceptance, documentation, preservation and transfer of information). Identification and discussion of activities to handle questions regarding sustainability in the different dimensions (e.g., measures for compensation and reducing resource consumption and GHG generation; cost optimisation; public participation, transdisciplinary, civil society, knowledge management). Cooperation and relevant past projects: IAEA nuclear security network	Nations sustainable development goals. Sustainability aspects are strongly coupled to societal aspects.
1.3.2 Skills and competence management	**NEW: Support programmes to develop and maintain the required technical and management skill base (core capability)** Expected outcomes and impact: An EU integrative KM initiative that supports the development, coordination and networking of a KM system for RWM organisations, Research Entities and other actors. Scope could include knowledge capture and dissemination for an updated European RWM state-of-knowledge; Support to National Programmes in their maintenance and expanding of nuclear competences, specifically in the field of RWM, that are required now and in the future for the safe operation of a RWM programme, including interim storage prolongation, transport, facility construction, closures and post-closure procedures; Assuring continued accessibility of European project documentations generated over the past 40 years; Identifying essential knowledge, essential for our generation and worth to be transferred to future ones; Applying sustainable informatics systems for knowledge management (up-to-date, to last several decades); Monitoring of the development of tacit knowledge transfer methodologies on a time scale of several decades (inter-generational transfer); Training of young student and non-nuclear specialist to become experts in RWM, supporting the decade-long RW implementation (inter-generational change); Providing input to identifying additional R&D activities through disseminating established knowledge and identifying residual knowledge gaps (complementary KM activities); Inter-linking national activities to promote a high-quality and fast knowledge transfer, thus promoting an efficient and indirectly more harmonised Europe-wide RW disposal implementation. Cooperation and relevant past projects: IAEA KM Assist Programme, the NEA (IGSC) Working Party on Information, Data and Knowledge Management, EURAD KM WPs, EURAD, PREDIS.	**KM** Realisation of a geological repository is a multi-generation project requires careful technical skill management. An integrated approach could develop means (methods, techniques and practices) to limit the loss of skill when projects are handed over or are delayed and experts are no longer available to organisations. The EURAD platform is well-placed to structure and organise radioactive waste management competence, knowhow, and capabilities on a European scale. This requires interaction with the main RWM players to create a robust KM system which fits the needs of the different actors.
1.3.3 International collaboration	**EU research infrastructure: To document the extent of European research infrastructure and competencies and establish conditions allowing for transnational access to and/or sharing of facilities and established networks.** Expected outcomes and impact: Improved understanding of the breadth, depth and accessibility of research infrastructure across Europe. Increased accessibility of RWM experts to EU programmes leading to faster implementation, impacting through of reduced costs and	**KM** It is important to identify competence, skill and infrastructure which is relied upon across Europe so that mitigation measures to ensure its maintenance are put in place. International collaboration and scientific exchange is a pre-requisite for the sustainable improvement of the state-of –the Art knowledge and

	avoid undue burden to future generations. Further outcome is preservation of expert knowledge through continuous learning from different programmes, combined with dissemination of knowledge from other programmes. Identify hurdles for harmonisation of regulatory approaches to develop a common view on RWM disposal implementation. Cooperation and relevant past projects: possibility to explore training / mobility exchange at some sites / URLs. ENSAR, ENSAR2, TALISMAN/ACTINET (past projects) and link to current OFFERR project. ENEF and HARPERS.	technologies. A network of state-of-the-art research infrastructures exists but could be more formalised to ensure critical infrastructures are maintained and developed for the future (e.g., hot labs, URLs, etc.).
	NEW: Development of a forum for a community of practice between LIMS and SIMS Expected outcomes and impact: Easier and SotA application of Spent Fuel management methodology for SIMS, leading to increased efficiency, cost effectiveness and safety of SIMS disposal strategies. Creation of a knowledge base in terms of waste management from pre-disposal to disposal phases. Identification of good practices or innovative processes that could be exported in other Member States. Cooperation and relevant past projects: ROUTES, HARPERS, and SoK developed within EURAD	**KM, Societal Engagement, Tailored Solutions** Topics to be addressed in such a forum would be the following: Elaboration of guidance on predisposal routes of challenging wastes (waste inventory, characterization, treatment and conditioning methods, disposal options), notably for chemotoxic waste and legacy waste; Development of guidance on radioanalytical, physical & chemical characterization; Collaboration to provide training and sustain competences in the field of radioactive waste management; Developments in the application or validation of scaling factors, as well as best practices, should be made available for small-inventory member states (SIMS), who often lack financial resources for their own development; Characterization of alpha containing wastes, where representative sampling is crucial for determination of DTM radionuclides; and Benchmarking exercise for WAC development.
	NEW: Identification of possible shared (and possibly mobile) solutions for radioactive waste characterisation, treatment or conditioning Expected outcomes and impact: Terms of reference for cost-effective solutions of SotA characterisation, treatment or conditioning solutions that could be shared, e.g., for SIMS, or other programmes. Note: Implementation of RD&D actions to support and develop the TRL of a given technology should be integrated with parallel activities identified in Domain 2.2.1 Characterisation and Domain 2.2.2 Treatment and Processing and 2.2.3 Conditioning. Cooperation and relevant past projects: ROUTES and ERDO.	**Tailored Solution, Innovation for Optimisation** Small-inventory member states (SIMS) often lack financial resources for the development of characterisation procedures and maintenance of the characterisation technologies for each waste type. Additionally, SIMS often have a variety of waste types but only at low quantities. Several types of mobile facilities might be needed: A mobile facility for RAW characterisation would provide SIMS with a cost-effective solution for SotA characterisation of their waste; and/or a mobile facility for solidification in specific matrices (such as geopolymers, alkali activated cements) which aim to better stabilise mainly of

		reactive metals provides SIMS with a cost-effective solution for conditioning of their waste increasing crucially safety.
1.3.4 Procurement and supply chain arrangements	No SRA activities identified.	
1.4 National inventory		
1.4.1 National radioactive waste inventory	No SRA activities identified.	
1.5 Management Solutions		
1.5.1 Integrated waste management routes and strategic options	**NEW: Assess possible strategies for SMR waste management and improve understanding for potential future quantities of waste arising from SMRs (and other new types of fuel), including the characteristics, location, ownership (responsible organisation) and amounts, in accordance with an appropriate classification scheme** Expected outcomes and impact: Perform orienting study on identifying potential (future) waste streams from Small Modular Reactors (SMRs, both light water based and advanced reactor types) considered for deployment in Europe, including fuel cycles considered for SMRs. Consider pre-disposal issues, including waste treatment, interim storage and transport issues. Assess societal impacts of waste handling and safety in localised regions. To identify challenges to the management and disposal of such wastes and enable early feedback to reactor system designers in order to mitigate associated risks. See also the NEW item in Theme 3 on SNF (Domain 3.1.1). Cooperation and relevant past projects: IAEA SMR Workshops, EC-ELSMOR project	**Implementation Safety, Innovation for Optimisation, Tailored Solutions, Scientific Insight** Development of new and advanced fuels and reactor technologies provides the opportunity for significant reductions in waste. However, there is a need to develop an improved understanding of future wastes and inventories that will arise from the use of new including advanced fuels, reactors and fuel cycles, due to the different characteristics of the fuels and wastes compared with those currently generated.
	NEW: Lifecycle assessment for waste management and application of the waste hierarchy Expected outcomes and impact: Improved and more sustainable management of facilities and projects to minimise wastes. Continued optimisation for implementing better treatment, processing and conditioning to support the waste hierarchy of encouraging greater reduction, reuse, recycling and free release (and less radioactive waste steams needing geological disposal). Improved analysis capability to assess options and underpin holistic cradle-to-grave waste management decisions. Includes application of the waste hierarchy to avoid/minimise secondary wastes. Cooperation and relevant past projects: PREDIS, EURAD	**Scientific Insight, Implementation Safety, Innovation for Optimisation** There is a need to develop tools and skills to support the application of circular economy principles to waste management, e.g., options for the reuse of secondary aggregate, research into sustainable fuel cycle options plus lifecycle analysis. European legislation and national policies in many countries adopt the concept of the waste hierarchy and require development, review and updating of waste management plans as part of the overall waste management strategy. The waste hierarchy sets out a

		priority order to support delivery of the best overall environmental option: prevention, preparing for re-use, recycling, other recover (e.g. energy recovery) and disposal. There is a need for further developing and spreading competencies regarding implementation of waste hierarchy strategy to reduce, reuse, recycle materials.
	NEW: Common analysis on management strategies for waste types (e.g., particular spent fuels or large volumes of low active long-lived waste) and small amounts of waste in SIMS Expected outcomes and impact: Reduce the number and range of wastes that do not have a disposal route. Identification of new options for managing challenging (orphan) wastes. Identify the needs and expectations of interested Member States in terms of long-term disposal of U/Ra/Th bearing wastes. Obtain an overview of national contexts and strategies for managing U/Ra/Th bearing wastes. Define common strategies to dispose of U/Ra/Th bearing wastes. Broaden application of experience and best practice (better insight into available treatment and conditioning options and disposal routes). Cooperation and relevant past projects: Related recommendations also identified in discussions as part of PREDIS. Work of the problematic waste integrated project team (PW-IPT) in the UK led by NWS. Conclusions linked to characterisation/treatment would inform subsequent R&D activities.	**KM, Tailored Solutions** Many countries have wastes that are challenging to manage because they do not meet the acceptance criteria for existing or planned disposal facilities. The management of Ra/Th/U bearing waste leads to various difficulties, particularly linked to aspects of characterisation and the lack of appropriate disposal routes. Whilst some countries are studying shallow depth disposal, others remain without any long-term solution. In this context, there is a need to share future disposal strategies and to discuss the associated difficulties.
1.5.2 Options and concept selection	**Guidance on methodologies for concept evaluation** Several WMOs will construct the repositories only decades in the future from now. Material sciences are making fast progress and could potentially contribute to rigorously different EBS concepts. A methodology and screening mechanism needs to be developed to rigorously identify and assess these.	**KM** Shared experiences on methodologies for evaluation and screening mechanisms for concept options (waste handling and EBS concepts) particularly to capture lessons learned on evaluation of novel or new materials (recognising that material sciences are making fast progress which could potentially lead to different EBS concepts in the future). This should address Member States who are also starting to build LILW repositories and surface facilities for pre-disposal management (treatment, processing). Therefore, the whole issue of what technologies to take advantage of (do it yourself or export across borders) should be covered here.

5.3 SRA Theme 2: Predisposal

Roadmap Theme Overview 2 provides background context and summarises existing knowledge in relation to the goal of delivering solutions to optimise the management of radioactive waste throughout the predisposal phases of the radioactive waste management programme, in conjunction with waste generators. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 2.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
Planning 2.1 - Planning predisposal management of materials and radioactive waste in close cooperation with waste generators		
2.1.1 Inventory	**NEW Knowledge management regarding existing studies on legacy and problematic waste inventories and capturing good practice in the management of inventory data, uncertainty treatment** Expected outcomes and impact: Understanding wastes that are not currently well characterised and are without identified waste routes. Improved knowledge of waste inventory helps improve methodologies to define radionuclide inventories, including DTM nuclides and activation assessments, use of radionuclide vectors and handling uncertainties, and thus further understanding evolution of the radionuclide inventory after disposal for impacts to the repository's safety case. Sharing of good practice in the management of inventory data can lead to cost effective data quality improvements. Cooperation and relevant past projects: EC PREDIS project, EURAD, ERDO (Legacy Waste Characterisation project), CHANCE.	**KM, Tailored Solutions** There is a need to understand the form of legacy wastes and associated radioactivity (e.g., whether liquids are present, any materials that may promote corrosion, gas generation etc.,) in order to better develop and validate processes for treatment, conditioning, packaging and disposal of such wastes. **Innovation for Optimisation, Scientific Insight** There is a need to gain a better understanding of certain waste inventories (e.g., legacy waste), which are currently either not well characterised or have not been well managed (treated and conditioned) and are known to pose safety issues for current treatment and conditioning technologies and disposal routes.
2.1.2 Waste acceptance criteria	**Develop guidance for the derivation of waste acceptance criteria (WAC) and benchmarking exercise for the process of WAC Development** Expected outcomes and impact: Shared knowledge and Improved understanding (via knowledge transfer) would lead to enhanced confidence in packaging and conditioning methods, and of the long-term environmental and radiological impact of wastes. Cooperation and relevant past projects: EC PREDIS project, HARPERS, EURAD	**KM, Implementation Safety, Societal Engagement** Development of good practice guides would capture existing approaches proven to work and potentially identify improvements that could be of benefit to a wide range of national programmes (e.g., by optimising RWM routes). Existing guidance is limited. Engaging with civil society on WAC management is an interesting way to provide transparency and maintain mutual trust about how the RW inventories are managed by MS.
	NEW: Dealing with non-compliant and challenging waste streams: methodology for demonstrating compliance with WAC Expected outcomes and impact: Create WAC to enable new waste forms (e.g., geopolymers, thermally-treated wastes, new immobilisation matrices, new package forms) to be developed	**Implementation Safety, Innovation for Optimisation** Increasing confidence in safety compliance, including regulatory acceptance. Ability to deal with challenging, new, and/or non-compliant wastes, to reduce hazards and to improve safety.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
	and disposed and enable new waste routes for certain waste types (e.g. liquid organics). Improve WAC definition for challenging waste streams, such as graphite. Accelerate regulatory acceptance and hazard reduction. Increasing waste owner confidence in waste routes and developing decision process for dealing with non-compliant wastes. Cooperation and relevant past projects: PREDIS, THERAMIN, CARBOWASTE, IAEA, ROUTES.	
2.1.3 Technology selection	**NEW: Selection of optimal technologies for existing and future waste streams** Expected outcomes and impact: Improved decision making for waste treatment and processing options , especially addressing for waste streams that do not have a route currently identified. Ability to compare technologies at different levels of maturity using tools. Cooperation and relevant past projects: PREDIS	**KM, Innovation for Optimisation** Improved decision making for implementing the correct technologies, including investments. Improved time efficiency, less costs, less material use, less by-product generation.
2.1.4 Waste hierarchy	*See Section 1.5.1 (Programme management)*	
Implementation 2.2 - Implementing predisposal management of radioactive waste to support key risk and hazard reduction, and to help reduce costs and save space at interim storage and disposal facilities		
2.2.1 Characterisation	**NEW: Development of characterisation methods and techniques for (conditioned) radioactive waste (and packages)** , Develop new methods and techniques to characterise the radiological and non-radiological (physico-chemical) quantitative content of (conditioned and non-conditioned) radioactive waste (and packages) including legacy/historic waste. Focal points are on improved non-destructive characterisation methods (e.g., for difficult to measure nuclides or for challenging waste package configurations), characterisation of physico-chemical content (presence of organics, complexing agents, etc.), phenomenological models, general improvements to make characterisation methods more available (including shared/mobile solutions), reliable, economic, robust and faster. Cooperation and relevant past projects: PREDIS, EC CHANCE project, EC MICADO project, ROUTES	**Scientific Insight, Tailored Solutions, Innovation for Optimisation** High quality characterisation data informs all subsequent stages of the waste management lifecycle strategy. There is widespread interest in efforts to improve the characterisation of certain wastes. Better general insight in waste characterisation as well as better availability of state-of-the-art solutions and approaches will improve understanding of waste compliance with WAC and are likely to result in a reduction of conservatism with respect to waste inventory (related to WAC).
	NEW: In-situ / in-drum waste identification, characterisation and segregation Development of new, remote, integrated and automated methods for in-situ identification, characterisation and segregation of material waste streams. In-situ characterisation of difficult to access areas, DSRS and orphan sources.	**Innovation for Optimisation, Scientific Insight** There are demanding challenges for gaining information from waste, packages and structures having difficult access for traditional characterisation sampling. Better informed decision-

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
	In-situ waste characterisation such as sharing of best practices on in-situ characterisation during remediation and site clean-up, can be considered as inputs. Methods would greatly benefit from robotics as well as AI-based data analysis and decision making related to (conditional) clearance of waste streams based on these characterisation methods. Cooperation and relevant past projects: EC decommissioning-related projects, EC MICADO project.	making on next steps for efficient remediation, dismantling and treatment benefits from such methods, resulting in lower costs, greater time savings and improved safety with less exposure risks.
	NEW: Development of innovative methods for scaling factors validation Expected outcomes and impact: Higher reliability of characterisation results due to higher reliability of scaling factors. There is a need for development of scaling factors (without introducing large uncertainties) that account for heterogeneity in terms of time, space, etc. Another development relates to a better uncertainty quantification and treatment when dealing with scaling factors. Lastly, although scaling factors are used now for radio-isotopes, there is also a need to scope their use for the physico-chemical inventory of waste (e.g., toxic compounds present in radioactive waste). Cooperation and relevant ongoing projects: ROUTES and PREDIS, EC Decommissioning-related projects.	**Innovation for Optimisation, Tailored Solutions** Application of the scaling factor methodology is a well-known and commonly applied method for the determination of difficult-to-measure (DTM) radionuclides. Nonetheless, this methodology is heavily dependent on the application of validated scaling factors.
	NEW: Development of methodologies for uncertainty and data management during characterisation. Expected outcomes and impact: . Characterisation data handling and measurement uncertainty management (e.g., through Bayesian approaches). New characterisation strategies for heterogeneous waste streams (notably legacy waste). Improved interpretation of characterisation results using artificial intelligence (AI) or machine learning (e.g., for attenuation correction) methods or geostatistical methodology techniques, e.g.,for representative sampling of challenging or heterogeneous waste streams. Cooperation and relevant past projects: ROUTES, CHANCE Work of the problematic waste integrated project team (PW-IPT) in the UK led by NWS.	**Innovation for Optimisation, Tailored Solutions, Scientific Insight** Interpretation of results obtained through application of characterisation methodologies and techniques greatly benefit from new and advanced approaches related to data simulation, uncertainty management, interpretation of obtained spectra, etc. A specific topic deals with the reliability of characterisation results utilising destructive methods which is heavily dependent on representative samples, especially with heterogeneous wastes. Sampling strategies need to allow variation across a waste stream to be adequately identified.
2.2.2 Treatment and Processing	**Better treatment and processing of problematic waste streams, including damaged fuel and/or damaged waste packages** Expected outcomes and impact: Improved waste treatment routes for graphite mixed waste, organic materials, reactive metallic waste, liquid waste, hazardous and toxic materials). Scope should include methods of decontamination and improved segregation. Minimise radiological	**Tailored Solutions, Innovation for Optimisation, Implementation Safety, KM** Processes for management of waste, fuel and packages damaged or degraded prior to disposal would help Waste Generators to evaluate whether aged wastes require re-processing and/or re-packaging and how to carry out this re-

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
	consequences and address waste acceptance criteria in the event that packages have aged and require re-processing or have become damaged prior to transfer to a geological disposal facility. Cooperation and relevant past projects: PREDIS, ROUTES	work. Early warning system need to be developed in order to detect damages and assist decision making for remediation.
	NEW: Flexible decontamination and improved treatment processes (including thermal treatment, and modular and mobile systems) Expected outcomes and impact: Moving technologies from the lab-scale to industrial-scale. Facilitate improved treatment and processing of new and different types of waste streams, including thermal treatment solutions, and the optimisation of thermally-treated product composition to increase waste loadings and/or improve wasteform performance and reduce volumes of secondary waste. Development of more flexible, modular treatment facilities and solutions. Optimised chemical and physical methods of treatment, especially including solutions for decontamination. Cooperation and relevant past projects: ROUTES, THERAMIN, PREDIS	**Tailored Solutions, Innovation for Optimisation, KM** Better solutions, more cost effective, less waste for disposal supporting waste hierarchy. Links through to the need for development of waste acceptance criteria for thermally treated products and the understanding of the long-term behaviour and chemical durability of thermally treated products.
2.2.3 Conditioning	**Developing novel conditioning technologies for new and problematic waste.** Expected outcomes and impact: Development of new and emerging conditioning solutions (to increase TRLs) for stabilisation and immobilisations of waste, e.g. geopolymers, ceramics, new admixtures. Develop novel methodologies and techniques to reduce the volume of waste. Identification and sharing of good practice in waste conditioning and packaging approaches for problematic wastes and new / future wastes. Address re-conditioning of legacy wastes and re-conditioning of bituminised coming from reprocessing. Cooperation and relevant past or ongoing projects: ROUTES, CORI, PREDIS, THERMAIN	**Tailored Solutions, Innovation for Optimisation, Scientific Insight, KM** A range of problematic wastes exist which require novel conditioning technologies supporting optimisation (including ion exchange resins, tritiated wastes, irradiated graphite, reactive metals, wastes containing high levels of I-129, sealed sources, plutonium residues, exotic fuels and bitumen sludges). Conditioning can ensure production of stable waste packages and readiness for disposal. Optimisation techniques addressed to reduce volume of secondary waste to enhance safety during transport and storage/disposal, to save costs, etc.
2.2.4 Storage	**Understanding of the potential for long-term storage as a management option for disused sealed radioactive sources.** Expected outcomes and impact: To understand the potential impact of improving technology for the treatment or re-use of disused sealed radioactive sources as an alternative to disposal. Identification of social and technical interrelated challenges related to long-term storage.	**KM, Tailored Solutions, Societal Engagement** Disused sources for which no recycling or repatriation options exist currently are required to be declared as radioactive waste and should be managed as such, in compliance with relevant international legal instruments, safety standards, and good practices. For small inventory programmes, with no disposal

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
	Cooperation and relevant past projects: IAEA Management of Disused Sealed Radioactive Sources, ROUTES	programme, long-term storage is the only currently feasible option.
	Ensuring safety and potential extension of operational lifespan of waste packages and structures associated with interim storage. Expected outcomes and impact: Identification, characterisation and management of uncertainties related to the performance of the final waste package (including the waste form) during prolonged storage, e.g., ageing, confinement integrity, handling constraints, including effects on specific materials of casks for dry storage of Spent Fuel. To support the safe management and safety assessment of existing storage facilities, actions needed for lifetime extension, design criteria for new storage facilities. Technologies can include remote monitoring system, non-destructive evaluation tools, digital twins, and data handling platforms (including AI) for decision making on package and storage durability performance. Cooperation and relevant past projects: ROUTES, PREDIS, Modern2020 *Note: This item also relates to the long-term waste package performance, See, for example, Sub-theme 3.1.*	**Implementation Safety, Innovation for Optimisation, Societal Engagement, KM** Lifetime performance assessment for safety. Ageing of waste packages and facilities nearing or exceeding the end of their design lifetime, therefore needing extended storage periods due to the lack of availability of disposal facilities. Such predisposal management issues may impact the initial state of the waste in a future disposal facility, as linked to the waste acceptance criteria and demands for pre-packaging. Improved monitoring will enable interventions to be made where required to the package or environmental conditions. Automation and remote monitoring will increase safety through minimising human interactions. Engaging with Civil Society on this topic would contribute to maintain trust on the predisposal steps of RWM and their connections with the disposal step.
2.2.5 Transport	*No SRA activities identified.*	
Optimisation 2.3 - Enhancing predisposal operations through iteration with waste generators and repository operators, to develop and deliver safe and cost-effective solutions		
2.3.1 Quality and management systems	*No SRA activities identified, as this is within Theme 1*	
2.3.2 Optimisation of radioactive waste predisposal activities	*No SRA activities identified, as this is within Theme 1.*	

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies or KM Needs of Common Interest	Drivers
2.3.3 Secondary waste management	*No SRA activities identified, as this is integrated within Theme 1 (1.5.1 life cycle assessment, waste hierarchy)*	

5.4 SRA Theme 3: EBS

Roadmap Theme Overview 3 provides background context and summarises existing knowledge in relation to the goal of developing an engineered barrier system, tailored to the characteristics of the waste and compatible with the natural (geological) barrier, that performs its desired functions, for the long-term disposal of radioactive waste. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 3.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
Wasteforms 3.1 - Confirm wasteform compositions, properties and behaviour under storage and disposal conditions, including radionuclide immobilization and impact on the disposal environment		
3.1.1 SNF	**NEW: Continue to expand the knowledge base for damaged spent nuclear fuel and/or the properties and long-term behaviour of fuels if subject to extended storage** Expected outcomes and impact: Enhanced confidence in safety and applicability of source term data (including for damaged fuel) by performing long-term experiments (>10-15 years) to investigate detailed processes and to verify the low dissolution rate of SNF under repository conditions. Knowledge sharing and standardisation of fuel test methods and models. Note that this need is linked to 2.2.4 Operational lifespan of interim storage facilities, and 2.2.5 Network on the implications of extended interim storage for nuclear waste transport. Cooperation and relevant past projects: EURAD	**Implementation Safety, Scientific Insight** Understanding of spent fuel evolution during interim storage and implications for its final disposal (source term characteristics, fission gas release) is critical component of the safety case. The existing knowledge base can be deepened using latest scientific insights and requires expansion to understand it applicability for damaged fuel and to extending the data range for different fuel types (burn-up, MOX, new fuels like accident tolerant fuels).
	NEW: Optimisation, safety and risk assessment of spent fuel (SF) management and disposal operations (including new upcoming designs e.g., ATF, SMR's), by characterising their physical and thermo-mechanical-chemical behaviour following state-of-the-art techniques (e.g., Machine Learning, AI). Expected outcomes and impact: Assessment and research of back-end properties of all fuel types used and foreseen to be used in EU. Assessment of the impact of various (existing and future) reactor designs (SMR, Gigawatt-scale reactors Gen-III, Generation-IV, VVER, CANDU) on the spent fuel management (i.e. inventory and property changes for VLLW to HLW), and research of needed knowledge. Validation required to support derived SF characteristics by state-of-the-art codes, against available experimental data (criticality, decay heat, dose, nuclide inventory) and development of characterisation instrumentation. Development of novel techniques to support safety analyses (digitalisation), while optimising processes for spent fuel management and disposal (Machine Learning, deep learning). Development of methodologies to numerically and experimentally investigate the evolution of SF mechanical properties during interim storage and transport.	**Implementation Safety, Scientific Insight** Accident Tolerant Fuels (ATF) are required by the European Taxonomy from 2025. The back-end implications of ATF have not been well investigated so far. Small Modular reactors (SMR) are widely discussed to be deployed in the near future. Due to the great variety of proposed designs, the impact on the back end needs to be investigated on the European level. Currently available experimental data and previous studies focus mainly on a subset of the expected SF inventory in Europe. Therefore, the identified technical and experimental gaps should be further studied (e.g., high burnup, MOX, hexagonal fuels). Validation is required to support derived SF characteristics. Machine Learning and AI should be considered to investigate the optimisation potential in various back-end operations and to strengthen the confidence on derived SF properties and related uncertainties.
3.1.2 HLW	No items identified.	

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
3.1.3 Cemented LL-ILW	**NEW: Understanding long-term behaviour of innovative conditioning matrices** Expected outcomes and impact**:** Better understanding of the degradation mechanisms and rates of innovative waste matrices in long-term interim storage and disposal conditions. Anticipate compatibility and potential interactions with disposal components and repository materials. Collect valuable inputs in order to define WAC associated with these innovative conditioned wastes and associated packages. Cooperation and relevant past projects: THERAMIN, ROUTES, PREDIS.	**Tailored Solutions, Implementation Safety** More innovative technologies and materials are being developed to treat and condition particular waste such as spent ion exchange resins, sludges, organic waste or even waste containing reactive metals (e.g., Al, Mg, etc.). However, the long-term behaviour of innovative matrices remains unknown especially in disposal conditions and there is a clear need to better determine their characteristics, and long-term durability and impact to the safety case.
3.1.4 Other wasteforms	No SRA items identified.	
Waste packages, for disposal 3.2 - Identify container materials and designs for each wasteform under storage and disposal conditions and confirm properties, behaviour and evolution under storage and disposal conditions		
3.2.1 HLW and SF Containers	**NEW: Waste package durability and long-term performance** Corrosion films (oxides, sulfides or biofilms) and the threshold environmental conditions (e.g. ammonia concentration) triggering stress corrosion cracking on the primary container material are still not well defined. The underlying mechanisms governing creep and stress relaxation mechanisms are also still the subject of debate. Hydrogen embrittlement is typically studied in conditions that are not representative of the conditions in a DGR (e.g., H2 charging or very high sulfide). Expected outcome and impact: better understanding of processes that can affect waste package durability and where improved understanding could lead to optimisation of container designs. Note: the topic “Improved understanding of the interactions occurring at interfaces between different barriers including waste packages in the disposal facility” from the previous SRA version is moved to subdomain 3.4.1.	**Innovation for Optimisation** Existing waste package design requirements are typically based on conservative assumptions with respect to the effects of perturbations or extreme evolution scenarios. Improved data and understanding for waste package evolution in more realistic conditions could lead to opportunities for material selection and package design optimisation, especially for programmes that assign a safety function to the primary container.
3.2.2 LL-ILW Containers	No SRA activities identified	
3.2.3 Novel Containers	**Developing alternative HLW, Spent Fuel and LL-ILW container material options and improved demonstration of their long-term performance**	**Tailored Solutions, Innovation for Optimisation**

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Expected outcomes and impact: Identification of alternative container materials or coatings beyond combined copper/cast iron or carbon steel, suitable for fulfilling container safety functions in current disposal systems and suitable for packaging novel wasteforms. There is also a need to explore new container designs for LL-ILW. Overall impact should be to improve the design basis for the container: constraints (loads and conditions) to be included/excluded from the design basis, methodology for defining the design requirements, (e.g., small-scale tests and their scalability), verification methods. Improve the design basis for the container: considering constraints (loads and conditions) to be included/excluded from the design basis, methodology for defining the design requirements, (e.g., small-scale tests and their scalability), and verification methods. Scope should include improved container production methods fulfilling the container design requirements and improved—quality assurance and requirements verification processes as well as quality assurance. Cooperation and relevant past projects: EURAD-1	A large body of work has been completed to demonstrate the feasibility and manufacture of corrosion-allowance container designs. Corrosion-resistant materials, and other container designs (coated containers, ceramics) are less developed, but further work would underpin the feasibility of their manufacture and the quality of the resulting designs. Need to Integrate digital techniques in innovative container, embedding information for the logistic and the inventory
Buffers, backfills, plugs and seals 3.3 - Identify appropriate buffer, backfill and seal/plug materials and designs, and confirm their properties, behaviour and evolution for the selected repository concept		
3.3.1 Buffers	**Characterised bentonite / clay-based material evolution under specific conditions to provide data on hydro-mechanical, thermal, gas transfer and chemical behaviour** Expected outcomes and impact: Enhanced understanding of post-closure safety considerations, focussing on remaining open issues (chemical effects, THM effects) of bentonite and clay-based materials. Improved characterisation of different phenomena, including variations of properties arising from barrier installation, hydration history, elevated temperatures and chemical influences (including microbial processes) on long-term evolution behaviour and gas migration. Understanding the THM evolution of bentonite during the thermal phase helps to set requirements on the minimum and maximum density of bentonite near the primary container and better justify the maximum temperature in bentonite. Cooperation and relevant past projects: EC BENIPA and BELBaR project, BEACON, EURAD	**Tailored Solutions, Innovation for Optimisation, KM** This is a mature domain, so optimisation and knowledge management of existing know-how are the main drivers. A wide range of bentonite/clay-based materials are available for potential use in deep geological repositories. To enable programmes to make best use of available resources, to optimise barrier designs and to inform the development of supply chain capabilities (material sourcing, demonstration testing) they require a good understanding of the critical properties and the full characterisation envelope, building on the existing understanding of bentonites / clay materials that are already well developed. During the early evolution (thermal phase) of a SNF repository, water and vapour redistribute in the vicinity of the canisters governing several processes linked to the sealing properties of bentonites, such as swelling, homogenisation of density differences, mass re-distribution, distribution of voids. Understanding these processes during the thermal phase means

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
		that we can better define the initial state and better predict the long-term evolution of the EBS.
	NEW: Developing the state-of-the-art methods of uncertainty management associated with buffer materials characteristics Expected outcomes and impact: Methodology for laboratory measurements will be one of the task outcomes. Cooperation and relevant past projects: EC project BEACON, EURAD.	**Implementation Safety, Scientific Insight** Past projects have shown significant variability of measured THM properties of buffer materials (such as swelling capacity, water retention properties, compressibility), which are key inputs needed for establishing correct EBS functionality. This difference was obtained even if tested on nominally identical samples in different soil mechanics laboratories. In addition, full-scale measurements in mock-up tests often show results inconsistent with laboratory measurements on small-scale samples.
3.3.2 Backfills	**Improved quantification and understanding of cement-based material evolution (including low pH cements) to improve long-term modelling and assessments for near-surface and geological disposal** Expected outcomes and impact: Increased confidence in simulations by reducing uncertainties in input data and understanding of key processes (for both young and aged materials), taking into account specific conditions for waste disposal, e.g., temperature, radiation, redox, chemical perturbations related to waste (e.g., sulphates, ammonium…) and considering hydromechanical behaviour (shrinkage and creep), and passive and active corrosion impacts. Benchmarking with the concrete industry and for new materials would be beneficial. Of particular interest is to understand and quantify cement-degrading substances and their long-term effect on concrete barriers. Sulphate and chloride cause cement mineral transformations and can be released over time from various common waste materials including sulfonated ion-exchange resins. Organic Ca-consumers such as oxalate and citrate are also present in many LILWs and leach Ca^{2+} from cement, degrading the materials over time. Cooperation and relevant past projects: EC CEBAMA project, EURAD-1 MAGIC WP, CORI	**Scientific Insight, Implementation Safety** Pure OPC will soon become unavailable in the concrete industry market because of CO2-emissions and other reasons. Fly ash is foreseen as the main additional cement component. This is a strong motivation for progressing work on cement systems. The new generation concrete materials and their performance from safety case point of view is relevant to many disposal facilities. The use of such materials for a variety of barriers in disposal systems (for near-surface and deep geological disposal) is of interest, including low-pH cements (which could be considered for backfills and or for new plug designs or pressure resisting walls. Disposal systems that rely on a chemical containment function by maintenance of alkaline pore-water over long-timescales require a good understanding of the changes in physical and chemical transport properties of the assumed cement-based backfill as a result of reaction with groundwater solutes (including aged and degraded and/or carbonated cements). Improved understanding of such processes could allow the development of more detailed numerical models and help bound uncertainty assumptions used in safety assessment models. For example, improved understanding for radionuclide interaction with degraded

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
		(carbonated) cement could improve current safety assessment assumptions.
	NEW: **Improved understanding of mixtures bentonite/crushed rock, bentonite/sand, sand/crushed rock** Expected outcomes and impact: Improved data and understanding of design requirements for disposal systems that are compatible with the use of mixed-clay-based backfills. Increased confidence in simulations by reducing uncertainties in input data and understanding of key processes including hydromechanical behaviour. Cooperation and relevant past projects: EC BEACON	**Innovation for Optimisation** Mixture with bentonite, crushed rock or coarse grained soils (sands) material is one of the key candidates for backfilling of the access tunnels and shafts within the repository. Similar to the buffer material, they should present depending of the repository design, low permeabilities, swelling potential to mitigate development of inhomogeneities forming preferential radionuclide transport paths and to reduce microbial activity, stability under increased temperature and stability over the repository timescale, not gas-tight, low deformations under loading. To date, investigation has mainly focused on bentonite as a buffer material in the form of compacted blocks and pellets. Further Investigation of mixtures, both experimental and numerical, is needed for the repository design optimisation.
3.3.3 Plugs and seals	**Improved understanding of the performance of plugs and seals** Expected outcomes and impact: To further understand the coupled THMC behaviour of plugs and seals throughout the post-closure phase and to develop improved modelling capability to provide reassurance over the long-term. Establish link to technical feasibility: By means of linking THMC process understanding, safety functions, technical requirements and actual production / emplacement it has to be ensured that plugs and seals will perform as required. This need is closely related to Domain 3.3.2 (and the need to improve quantification and understanding of cement-based material evolution to improve long-term modelling and assessments). Cooperation and relevant past projects: EC projects RESEAL II, DOPAS, BEACON	**Tailored Solutions, Implementation Safety, Societal Engagement** The specific requirements of plug and seal components will depend on their location within a disposal system and site-specific conditions such as geochemistry, the groundwater flow regime, the mechanical stability and the thermal properties of the selected geological environment. Mature plug and seal designs exist for specific disposal systems with acceptable performance. Further understanding would enable tailoring of plug and seal designs for different system requirements or for the optimisation of existing concepts. Demonstrating the performance of plugs and seals is important to build/maintain trust about the feasibility of a safe closure of a disposal facility. Engaging with CS about this topic is thus important.
EBS System integration 3.4 - Confirm integrated EBS system understanding and identify compatible EBS designs and materials for facilities containing multiple wasteforms		
3.4.1 EBS system	**NEW: Gas generation from metallic components and potential impacts on the disposal system.**	**Innovation for Optimisation**

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Expected outcomes and impact: Better quantification of gas generation function of time and maximum gas pressure in the repository. Cooperation and relevant past projects: FORGE	The use of new materials instead of metallic materials to decrease the hydrogen source term could lead to optimisation of disposal system durability.
	Improved description of the spatial and temporal evolution of transformations affecting the porous media and degrading materials in the near-field of HLW and ILW disposal systems. Expected outcomes and impact: Improved geochemical models used in near-field modelling through numerical and experimental characterisation of their evolution and identification of the key THMC evolution processes (including metal corrosion / secondary phase formation, cement alteration and alkaline perturbations on the host rock, and other coupled interactions). An important process for inclusion is unilateral hydrostatic pressures affecting concrete barriers during repository resaturation and advancements to allow existing models to interact. Include/Improve these coupled interactions in reactive transport models. Also important is an improved understanding of the interactions occurring at interfaces between different barriers including waste packages in the disposal facility. Knowledge of the physical and chemical transformations due to coupled processes at the interface between waste packages and different barriers and materials and development of pore-scale models describing the impact on gas generation, radionuclide migration and fluid transport, potential clogging in bentonite/cement or host-clay/cement interfaces or increase in porosity in other interfaces under real repository conditions. Improved understanding of the spatial extent and evolution with time of oxidative transients (inc. during construction and operations, notably with regards to corrosion of metallic components, as well as the possible impact on safety functions). Cooperation and relevant past projects: EURAD-1	**Scientific Insight, Implementation Safety** Re-saturation and mechanical evolution of EBS materials is a complex process which depends upon the properties both of the buffer and the host rock, as well as upon the influence of thermal loading. The post closure environmental safety case requires a sufficiently detailed understanding of mechanisms and chronology of near-field evolution over long timescales. In disposal systems that do not rely on a high integrity container / physical containment function there is high emphasis placed on understanding the long-term evolution using component models which to-date are relatively simplistic. To enhance confidence and to take full advantage of improved computing and advances in digital twins, ongoing work could improve understanding of more complex systems and lead to improved scientific insights on key controls.
	NEW: Understanding pore fluid evolution Expected outcomes and impact: Test cases for the calibration and evaluation of coupled reactive transport models (RTM) using evolving source term complex fluid chemistries. Understanding the impact of differing groundwater compositions, particularly that of salinity on cement leaching. Emphasis on comparing the degradation of OPC vs LAC's (low alkaline cements) derived concretes and the subsequential generation of alkalinity and pH, together with the long-term, spatial and temporal, chemical evolution of the pore fluids; microbial impacts; redox conditions, the induced changes in primary and secondary phase formation and dissolution; and the associated impacts on radionuclide migration, sorption and re- mobilisation within the repository, EDZ and CDZ. Principle aim will be to provide test cases for the calibration and	**Scientific Insight** Reactive transport models are rapidly evolving but require data sets for a broad range of pore water evolution scenarios so that they can be useable for supporting a range of disposal programmes, disposal concepts and siting scenarios.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	evaluation of coupled reactive transport models (RTM) using evolving source term complex fluid chemistries. Cooperation and relevant past projects: ACED	
	NEW: Demonstration of long-term performance of a specific barrier using large-scale mocks up and complete digital representation Expected outcomes and impact: Improved demonstration and modelling toolkits to support the evaluation of barrier performance. Cooperation and relevant past projects: FEBEX, full-scale heater test	**Scientific Insight, Innovation for Optimisation** Advancements in digital twins to simulate long-term degradation of disposal systems require continued large-scale experiments and / or monitoring data.
3.5 Co-disposal	**Improve understanding of the key requirements for managing co-disposal** Expected outcomes and impact: To optimise the use of geological facilities by enabling disposal of wastes with a variety of compositions and properties requires in depth knowledge on possible mutual interactions arising from different waste inventories and their evolution with time. Cooperation and relevant past projects: NWS(UK) work on interactions.	**KM, Tailored Solutions** Programmes with complex waste inventories will need to ensure disposal areas (in a co-disposal facility) do not have detrimental impacts (chemical, thermal) on one another. Governance and management in different co-disposal scenarios have to be identified. Networking and sharing is the main driver to complement existing cooperation that is supported via the IGD-TP.

5.5 SRA Theme 4: Geosphere

Roadmap Theme Overview 4 provides background context and summarises existing knowledge in relation to the goal of assembling geological information for site selection, facility design and demonstration of safety. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 4.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
Site Description 4.1: Provide, or confirm a description of the natural barrier and how it contributes to high level safety objectives (Site description)		
4.1.1 Site descriptive model	**Developing models or digital representation of the hydrological system** Expected outcomes and impact: To increase understanding of groundwater evolution, including composition and flow, relating to past and future events, such as climate change, glaciation and related subglacial erosion and permafrost formation. Use available geodata to construct a digital representation of the host rock and identifying/investigating how uncertainties (e.g., related to mineralogy, sorption capacity, water content) influence THMC-B behavior. Outputs should include improved understanding of reaction and solute exchange with the rock matrix. Cooperation and relevant past projects: ERDO (Deep Borehole Disposal Project).	**KM** Starting during site characterisation, programmes are required to develop site description models, including models of groundwater evolution; in this field, a first approach to the machine-learning tools, as a powerful alternative for numerical models in hydrological science, would be very useful. **Implementation Safety, KM, Innovation for Optimisation, Societal Engagement** Starting during site characterisation, programmes are required to develop site description models, including models of groundwater evolution; in this field, a first approach to the machine-learning tools, as a powerful alternative for numerical models in hydrological science, would be very useful. Although site-specific, comparison of overall methodologies and benchmarking of approaches (also related to other scientific non-nuclear fields) would be of benefit to all programmes, especially sharing of experience from advanced programmes.
4.1.2 Bedrock transport properties	**Increased understanding of gas reactivity and migration in different host rocks and development of two-phase flow numerical codes to increase gas transient representation.** Expected outcomes and impact: Further understanding of gas generation, reactivity and migration through the EBS and far field, including the fate of reactive gases (including upscaling from laboratory / URL studies) and the mechanical behaviour of host rock. Scope to consider carbon-14 migration, gas flow in EBS materials at elevated temperatures, gas interactions between packages and backfill, the impact of engineering design on gas migration, refined models of gas migration, including the treatment of uncertainty arising from the nature of the geological environment. Improvements to two-phase flow models which may be used at the	**Implementation Safety, Scientific Insight** Various gases will be produced from waste and engineered barrier components in HLW/SF and LLW/ILW after closure. A better understanding of the interaction of the gases produced with the EBS and host rock materials would provide input for the development of waste package and EBS barrier specifications and optimise repository layout if necessary. A better understanding of the interaction of the gases produced with the EBS and host rock materials would provide input for the development of waste package and EBS barrier specifications and optimise repository

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	disposal scale by increasing the level of coupling with mechanics and radionuclide transfer (solute and gaseous) is of interest.. Cooperation and relevant past projects: EC CAST and GASNET Projects, EURAD	layout if necessary. Continuous advancements in experimental techniques and specific sensors could enhance confidence in existing data sets, especially those acquired at low limits of detection.
	NEW: Improved understanding and quantification of factors affecting groundwater flow and retention Expected outcomes and impact: Improved understanding and quantification of factors such as fracture internal variability, channelling, diffusion into stagnant water, dead-end zones and their influence for matrix diffusion and retention. Cooperation and relevant past projects: See, SKB, and Posiva Documentation	**Scientific Insight** Required to enhance confidence in assumed performance assessment assumptions and parameters.
4.1.3 Biosphere model	No SRA activities identified	
Perturbations 4.2: Characterise the potential impact of disposal facility construction, operation and closure on the natural geological barrier)		
4.2.1 Perturbations	**Improved understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration** Expected outcomes and impact: Improved understanding of the nature of the organic molecules generated by the organic waste or admixture degradation, their stability with time, their effects on radionuclide migration, organic mixtures, the nature and release rate of organic compounds resulting from polymers radiolysis and hydrolysis, and implementation in a reactive transfer model. Note that work to consider the influence of organics is also relevant to domains in Theme 3 since for some disposal systems the organic complexing agents originate from the waste and their impacts has to be take into consideration in both the near field and far field (for DGR and surface disposal). Cooperation and relevant past projects: EURAD-1	**Implementation Safety, Scientific Insight** Waste groups containing organics exist across Europe, and material options with potential operational benefits (that contain organics) continue to be considered for potential use in DGRs. In such systems the potential for organics to cause perturbations are typically captured in sensitivity calculations. For systems containing naturally occurring organics (e.g., in the natural geological barrier), which is not treated as a perturbation, their influence on reference scenarios must also be understood.
	Improved understanding of the role of colloids and their influence on radionuclide migration Expected outcomes and impact: Experiment data and model development for colloid generation and transport, including transport parameters for inorganic colloids and radionuclide/organic complexes.	**Implementation Safety, Scientific Insight** The effect of colloids on the transfer of radionuclides in the case of clay host rocks is not significant in particular because of the pore structure. For other systems, colloid-facilitated radionuclide transport may be of significance if several criteria

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Cooperation and relevant past projects: EC project BELBAR	are met and is highly dependent on the assumed prevailing environmental conditions. Advancements in experimental techniques to quantify colloids and their influence on radionuclide specification and sorption properties (in complex, representative disposal conditions) would enhance confidence in current assumptions used in safety assessments.
	NEW: Improved understanding of the transport of, and geochemical alterations resulting from, the migration of cement (Ordinary Portland Cement, OPC) leachate in fractured bedrock Expected outcome and impact: increased understanding and improved predictive capability of the degradation of cement, the potential sealing of fractures, and its effect on available solute transport pathways and radionuclide sorption in fractured bedrock.	**Innovation for Optimisation** Internationally, reaction between cementitious materials and clay-rich materials (e.g., bentonite buffers) remains an issue of uncertainty. It is possible to limit the use of cement and concretes (e.g. Ordinary Portland Cement, OPC) in a given disposal area to minimise the amount of cement leachate that might adversely affect the performance of other materials. As an alternative, some repository concept designs have adopted various 'low' pH cement/concrete and grout formulation with a porewater pH below 11. However, since OPC is the most commonly used cement in mining and construction industries, further work to understand where it could be utilised without detrimental affects, could reduce costs and increase the safety of workers during the construction and operation of a facility.
Long-term stability 4.3: Provide, or confirm a description of the expected evolution of the geosphere (including the repository) in response to natural processes and future human actions		
4.3.1 Geological and tectonic evolution	**NEW: Improved understanding of the geological processes governing European ground motion (glacial cycle related seismic processes, faulting, creep, erosion)** Expected outcomes and impact: Compilation of the state of knowledge and increased knowledge of faulting, including seismic activity and aseismic creep and erosion. Improved understanding to support modelling of future geological and tectonic evolution. Care is needed to focus on generic understanding and application of theory without identifying issues specific to each country. It is explicitly noted that when capturing the state of knowledge on scientific aspects, evaluation of regional data and taking into account the capable faults in the context of safety is the result of a dialogue between the regulator and the WMO and is outside of the scope of Joint Programming.	**Scientific Insight** There are knowledge gaps related to crustal movements related to glacial cycles. The concept of capable faults needs to be better understood, both regarding their spatial and temporal distribution. Topics have been considered in some countries in detail, but the European wide view could be beneficial. **Implementation Safety, Innovation for Optimisation** Geological studies for the evaluation of long-term stability of the host-rock are important to enhance confidence in safety assessment. Future stability of the host rock guarantees the long-term stability of geological barrier. Review of novel

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
		methodologies for geological evolution assessment represent a further advancement in nuclear safety studies.
4.3.2 Climate change	**Enhanced treatment of climate change, land-use and parameter derivation in biosphere models** Expected outcomes and impact: To enhance understanding of site evolution (landscape, hydrology, biosphere) at several space and time scale for the different types of disposal so as to improve safety case confidence. Cooperation and relevant past projects: EC projects BIOCLIM, BIOMOSA, IGD-TP Project on climate change and its integration in the safety case.	**KM** Climate change science is rapidly evolving and continuous integration with the methodologies for treatment of the long-term stability of the geological barrier (and biosphere models) is required. To justify/prove the safety of geological disposal to stakeholders, it's very important a more deep integration among different fields (climate change, biosphere, hydrological evolution, etc.) for the correct evaluation of long-term stability of the host-rock. Civil Society is concerned by the impact of climate change and engaging with CS on this topic is thus appropriate.
4.3.3 Future human actions	No SRA activities identified	
Geosynthesis 4.4 Provide a geoscientific synthesis with geoscientific key information with respect to long-term safety and repository concepts (layout and construction)		
4.4.1 Geo-datasets and conceptual models	**Developing a geochemical model for volatile radionuclides.** Expected outcomes and impact: To develop a geochemical model for a non-saturated system describing the distribution of volatile radionuclides between surface films of water, the aqueous phase and the gas phase, and to develop understanding of the capacity of host rocks and cement-based materials to interact with mainly 3H and 14C. Cooperation and relevant past projects: EC project Carbowaste, CAST	**Implementation Safety, KM** Further development of models would enhance confidence in performance assessment model assumptions.
	Improved understanding of the processes of fracture filling. Expected outcomes and impact: Further understanding of fracture filling, including modelling of the composition of fracture filling minerals and the associated mechanical strength of the fillers as a function of temperature and time. The scope should include not only fractures, but also the impact on the first few mm of the fracture adjacent rock to which the fracture fillings are associated. The disturbed zone is also of importance for rock mechanics.	**KM, Scientific Insight** Several materials are considered for use in grouting and sealing. The injection of sealants, such as silica sols are sometimes considered during construction and operation. Cement-based materials are also often used for this purpose. Depending on the design of the disposal concept, and extent of facture filling required, programmes need to make a choice on options and

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Cooperation and relevant past projects: EC CROCK project	also to understand that the materials will not have a detrimental impact on long-term safety (e.g., contribution towards a disturbed zone).
	Continued development of geosphere transport models Expected outcomes and impact: Improved understanding of the impact of rock-matrix diffusion on radionuclide travel time through the geosphere. Improved representation of the transport of contamination through the geosphere in support of the safety case. Improved understanding of the influence of temperature on radionuclide migration and representation of effects in geochemical models. Improved representation of sorption mechanisms and coupled chemistry / transport processes for various media, at all scales. Cooperation and relevant past projects: EC CatClay project, FUNMIG, MIND, EURAD	**KM, Scientific Insight** Improved understanding would enhance confidence in performance assessment model assumptions.

5.6 SRA Theme 5: Design

Roadmap Theme Overview 5 provides background context and summarises existing knowledge in relation to the goal of designing a facility that fulfils safety and security requirements and that can be practicably constructed, operated and closed. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 5.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
Design 5.1: Design and develop a disposal system for the national radioactive waste inventory		
5.1.1 Design requirements	**NEW: Improve the methodologies for assessing the concrete linings mechanical loading evolution** Expected outcomes and impact: To improve understanding of the temporal and spatial mechanical loading evolution of the concrete structures level. The scope is to consolidate the mechanical analysis of different monitoring/testing approach used on different existing URLs experiments, while considering the construction conditions (structure construction sequences, concrete control program, tolerances, …), and the intrinsic concrete behaviour. It permits to enhance the mechanical evolution description on the structure scale evolving in equilibrium with the host rock mechanical behaviour. Cooperation and relevant past projects: MAGIC	**Implementation Safety, Innovation for Optimisation.** Consolidate the mechanical design margin of the lining structures while acting on a better understanding of the mechanical loading evolution on different existing URLs lining experiments.
	NEW: Development of guidance for the implementation of deep borehole disposal, including their safety case development Expected outcomes and impact: Set up a guidance for safety case of DBD. Requirements for the development of a safety case for DBD (comparison with GDF notably). Specific issues to be tackled in case of DBR (emplacement of waste, packages, safety barriers, etc.). Overall, this would lead to an improved Improve technical readiness of DBD solution, new potential solutions for countries with a small inventory, optimisation of RWM routes, and development of sustainable governance solutions tailored to the needs. Impacts would also contribute to knowledge management among different actors and build new understanding. Cooperation and relevant past projects: EURAD, Collaboration with the SITEX Network, IAEA and the Deep Borehole Disposal Centre (USA).	**KM, Tailored Solutions, Implementation Safety, Societal Engagement** Deep Borehole Disposal (DBD) could be a feasible option for specific waste groups, e.g., for the disposal of high-level waste, especially for some small inventory Member States. The option might also be optimal for shared solutions. At the moment the safety case development of DBD is not at the same level as its technical implementation. Developing a safety assessment / safety case for a "new" type of disposal concept is a complex and long-term process in which pluralistic stakeholders could be engaged (Civil Society included).
	NEW: Conditions for Closure Interest in activities (networking and RD&D) about how to establish and verify the conditions for closing a repository and the post-closure monitoring options available. Another aspect of	**KM, Innovation for Optimisation, Implementation safety** Possible options/plans to move from an active to a passive site management have to be assessed, as well as the possible knowledge preservation programs. For instance, concepts for

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	interest is the assessment of what can be left in a closed repository: e.g., steel safety nets, rock anchors etc. Expected outcomes and impact: To improve the understanding of the performances, at different scales and under particular boundary conditions, of materials (e.g. bentonite) and components foreseen for closing repositories. By engaging multiple actors in such activities (Civil society included), a mutual understanding could be developed for instance on possible methodologies to establish and verify conditions on the performance of these materials before moving towards a closure phase.	closing investigation drill holes, shafts and driveways could be addressed. The surveilance of the closure effectiveness seems important, especially for boreholes covering high flow fracture - risk of concrete/bentonite erosion. The topic "Conditions for Closure" is of increased importance when proceeding towards implementation, thus relevant in the future. It is also relevant for near surface or surface disposal systems. **Societal Engagement** Closing a repository is an important decision requiring trust between all the stakeholders, Civil Society included. Engaging with the Society about the identification of possible options/plans and conditions to close a repository in a safe manner is thus important.
5.1.2 Design specifications, facility-scale	No SRA activities identified	
5.1.3 Design specifications, component scale	No SRA activities identified	
5.1.4 Design qualification	No SRA activities identified	
Constructability, demonstration and verification testing 5.2: Demonstrate and verify that facility components and barriers can be practically manufactured, constructed and installed in accordance with detailed design requirements and specifications		
5.2.1 Pilot-scale, full-scale testing, and active commissioning	**Verify robustness of disposal system designs using large scale mock ups** Expected outcomes and impact: To verify the robustness and demonstrate feasibility and performance of disposal facility designs and to demonstrate the capacity to build some complex components such as seals or the engineered barriers for geological disposals and test covers for surface disposal facilities.	**Implementation Safety, Innovation for Optimisation, KM, Societal Engagement** Large-scale demonstration programmes have been completed or are ongoing internationally at URLs and large demonstration facilities across Europe. They provide good opportunities to interact between stakeholders on the robustness of the system and thus to build and maintain trust. Decades-long cooperation

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Cooperation and relevant past projects: EC Projects ESDRED, FEBEX, FUNMIG, DOPAS (and many more).	between programmes to co-invest in such large-scale demonstrations has proven to be a good use of resources. Owing to the high cost of establishing this demonstration facility infrastructure and know-how, shared facilities and ongoing cooperation would be of cost-benefit to many programmes. Pilot-scale / full-scale tests are also needed for digital twin verification.
5.2.2 Optimisation (of the facility components and design)	**Optimisation of backfilling and other major implementation processes, including waste emplacement, retrieval and sealing technologies.** Expected outcomes and impact: To characterise at various scales (from laboratory scale to demonstration at full scale) the capability of the backfill material to meet the main requirements. This would require the study of mixtures between excavated rock with some additives such as cement to improve mechanical properties or bentonite to increase swelling capacity. Effects of long-term storage should also be studied as it could lead to storage recommendations. Cooperation and relevant past projects: EC Project DOPAS.	**Innovation for Optimisation, KM** Closure materials and processes related to backfilling have one of the highest potential impacts towards improving implementation throughput rates, operational safety, carbon footprint and overall cost. Sharing of good practice and latest innovations would support all programmes to optimise their own approaches and facility designs.
	NEW: Design optimisation and justification for facility components using digital representation. Expected outcomes and impact: Demonstration that a repository can be constructed and will fulfill certain (safety) functions by taking monitoring data from either existing URLs or (in the case of surface repository) a test multi-layer cover and making a digital representation of the as-built URL/test cover. Cooperation and relevant past projects:	**Innovation for Optimisation** Design justification / optimisation but the issue of designing of a multilayer cover based on large-scale mock-ups and modelling is an important topic for surface disposal. This links to the multilayer cover which is discussed in section 5.2.4 but only from the perspective of digital twins.
	NEW: Self-sealing in natural and engineered systems Expected outcomes and impact: Understanding sealing behaviour of discontinuities is key to assessing the longevity of safety functions within repository systems. Cooperation and relevant past projects: FORGE, CEBAMA	**Innovation for Optimisation, Scientific Insight** There remains considerable uncertainty surrounding the self-sealing of natural and engineered materials, as highlighted in previous frameworks (e.g., FORGE, CEBAMA, EURAD). This includes self-sealing behaviour of multiple features such as, (i) evolution of natural materials (e.g., faults, fractures, EDZ), (ii) behaviour of induced interfaces (engineered-engineered, natural-engineered) and their impacts on THMCGB behaviour. Improved

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
		understanding for allow for tailored solutions for optimisation of discontinuity behaviour.
	NEW: Optimisation of EBS geometry including high temperature consideration Expected outcomes and impact: To date, a large amount of research focused on improving the understanding of EBS buffer and canister materials, including the behaviour of bentonite under high temperature > 100 ˚C has been completed (this is a primary topic of WP HITEC within EURAD I). The outputs of this research are used to consider optimisation of material thicknesses combined with thermal modelling to establish minimum separation distances between waste packages and disposal areas (tunnels or holes). Thermal dimensioning tools can support programmes to evaluate potential sites to make early footprint calculations, and thereafter to incorporate site-specific data to allow for optimisation of disposal facility designs (estimate layout configurations). Cooperation and relevant past projects: EC project BEACON, EURAD, WMO toolkits for thermal dimensioning of underground facility layouts	**Innovation for Optimisation** Decay heat from fuel is one of the most important factors for establishing how much fuel can be emplaced in a container, how far apart containers need to be arranged in a disposal area, and how much cooling of fuel is needed before disposal (e.g., at an interim storage facility) – which all have a significant impact on overall cost of a disposal facility. To ensure that specified temperature limits are respected, and thus to minimise detrimental impacts of heat on the functional performance of the EBS or host rock, thermal modelling is required. Simplistic thermal models exist, but improvements could be made that might allow for progressive optimisation of the facility designs. Optimisation of EBS geometry considering the knowledge obtained in previous projects will be a computationally highly intensive task, where non-linear THM material models will have to be employed within coupled finite element codes to search algorithmically for the best geometry of individual canister shafts and their positioning and distance within repository.
5.2.3 Manufacture, inspection and testing	**NEW: Developing state-of-the-art on the methods of uncertainty management associated with EBS materials characteristics and concrete structure long term behaviour** Expected outcomes and impact: Recommendation and best practices for EBS material characterisation and for concrete structure (support, lining…) behaviour characterisation (taking into account the long life of such structure) and QA management. Cooperation and relevant past projects: Advanced Programmes Material Characterisation, EURAD MAGIC	**Innovation for Optimisation** Custom bespoke methods are widely used for EBS material characterisation. Even if standard methods are used they are very sensitive to minor variation in procedures leading into different results. For concrete standard methods exist but have to be adapted to the specific requirements and needs for the monitoring /inspection
5.2.4 Robotics	No SRA activities are identified; however, it is recognising by EURAD in this update that the fast advancement of robotics and the safety offered by automated operations provides opportunities to improve the implementation disposal facility operations. As such robotics (and automation) is a domain that could be considered in future work in relation to many of the needs	

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	listed in this SRA, e.g., an implementation action that could be considered within future project proposals.	
5.2.4 VR / Digital Twin	**NEW: Improve toolkits to make a digital representation (multi-physical digital twin) to support the evaluation of facility design** Expected outcomes and impact: Toolkits (unified and integrated system of tools) to demonstrate that a repository can be constructed and will fulfil certain (safety) functions, that multiphysical behaviour of disposal is as expected (and provide decision-making tool). It could be addressed by the use of monitoring data from either existing URLs or (in the case of surface repository) a test multi-layer cover, and making a digital representation of the as-built URL/test cover. The focus should not be to develop a common multi-physical digital, but to develop/benchmark associated tools such as Artificial Intelligence (AI) for data mining and scientific codes. Cooperation and relevant past projects: EURAD Digital Twin Community of Practice	**Innovation for Optimisation, Tailored Solutions, Societal Engagement** RD&D supporting the emerging digital transition within the DGR field is anticipated. An integrated assessment basis needs to be developed combining software tools (digital model, grid CAD/Mesh tool, numerical codes with their couplings, post-treatment) that so far have hardly be coupled before and that are covering various disciplines (geo-domain, performance assessment, engineering and economics). Applications aiding the coupling of these models, and managing interoperability, the use of proxy models, data mining, machine learning, etc can support this. Benchmarking of methods and interoperable tools in the whole chain of tools will increase confidence in their use.
	NEW: Artificial intelligence Expected outcomes and impact: to improve the distinction between artificial intelligence and robotics, and increase the coupled multiphysical knowledge of the disposal, by improving numerical simulation and data treatment of big heterogeneities (data fusion…). To explore possible applications of artificial intelligence in planning and realization of nuclear waste disposal (e.g. simulations, sorting, logistics, risk assessment, safety) monitoring could also be included especially in comparing and integrating in real time data from sensors to those from numerical simulation. Practical use of artificial intelligence under consideration of safety aspects (e.g. surveillance and control of systems based on artificial intelligence). Sociotechnical aspects (e.g. relation between human and artificial intelligence, working with systems based on artificial intelligence, interaction between human, technology and organisation) could be explored. Technology assessment (e.g., Collingridge dilemma; path dependency, termination, social acceptance) is required. Overall an initial strategic study on this domain could determine possible future research topics.	**Implementation safety / Innovation for Optimisation** Application of gaussian process, neural networks, model reduction, and surrogate models in general are an emerging field and its potential for use in radioactive waste management should be explored and benchmarked.
Security and safeguards 5.3: Prevent theft of nuclear material or sabotage of nuclear facilities and protect sensitive technology, software and information		
5.3.1 Safeguards	No SRA activities identified	

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
5.3.2 Security and physical protection	No SRA activities identified; however, it is reinforced by EURAD in this update of the importance of international cooperation (as largely led by the IAEA) between Members States in relation to security and physical protection. The importance of this domain has been highlighted by College members and by representatives of civil society organisation during EURAD-1.	
5.4.1 Construction and non-radiological safety	No SRA activities identified	
5.4.2 Normal operations safety	**NEW: Operational Safety of a DGR** There is interest in several R&D and networking studies about the operational safety of a Geological Disposal Facility. For instance, the following aspects could be addressed: • Regarding the combination of conventional and nuclear safety what are the key measures to consider when defining the layout of a GDF? • How to develop / validate a safe waste emplacement strategy in a repository? How to link it with the safety case and the safety assessment? Evaluation and possible management of the risk associated to the thermal reactivity of bitumen waste disposed of in a GDF (investigation of bitumen material formulation and performance by sample production, characterisation...). This topic is linked with "assessment of the risk of fire and explosion" below.	**Implementation Safety** A GDF is a very particular nuclear facility where several underground operations will occur. It is important to exchange and develop a mutual understanding about how conventional & nuclear safety can be combined in such an underground environment.
5.4.3 Accident safety	**Improve accident management and emergency preparedness (including in the conditions of external events, e.g., earthquake, flooding, storms, lightnings and other)** Expected outcomes and impact: To assess the impact of fire or explosions on the underground systems during the operational phase and the impact of external events (earthquake, flooding, storms, lightnings and other) and to improve the understanding of potential safety issues with regards to RWM, including disposal.	**KM, Innovation for Optimisation, Societal Engagement** Accident management and emergency preparedness is not only needed to support human safety (operators and the public), but experience from significant nuclear facility fires and accidents and from more minor routine accidents has shown that it can have far-reaching environmental and cost effects. Engaging with CS on this topic is important
5.4.4 Criticality safety	**NEW: Experiments and benchmarking to support post-closure criticality safety assessments.** Expected outcomes: develop the database such that criticality safety can be conducted on more realistic assumptions (alleviating some of the current conservative assumptions). Cooperation and relevant past projects: IGD-TP Post Closure Criticality Safety project	**Innovation for Optimisation** Criticality safety assessments typically assume that the fissile material is in its most reactive condition, which is usually at maximum enrichment with no irradiation. Fission

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
		products and actinides are formed during irradiation of the fuel in the reactor, a process which also tends to reduce the overall concentration of fissile material. Accounting for the resulting reduction in reactivity is known as 'burn-up credit' and can provide significant increases in derived safe fissile material limits. While the methods and responsibility to evaluate criticality safety is an implementer matter, a wider characterisation of certain aspects of SF and benchmarking of the findings with computer codes could support the further application of burn-up credit to disposal operations.
Monitoring and retrievability 5.5: Establish and implement an overall plan for meeting with national requirements for monitoring, and if required, reversibility and/or retrievability requirements.		
5.5.1 Baseline monitoring	No SRA activities identified	
5.5.2 Monitoring with regard to onsite investigation, construction and operations	**Developing monitoring strategies and innovative monitoring techniques for the operational and closure phases** Expected outcomes and impact: To capitalise on recent advances in monitoring technologies by developing, trialling, and assessing a range of monitoring strategies utilising state-of-the-art cost-efficient monitoring technologies. To investigate the impact of monitoring technology on the performance of a range of disposal systems. To provide reassurance of conditions following closure by identifying possible parameters for monitoring during the post-closure stage up to the end of institutional control.	**Implementation Safety, Innovation for Optimisation, Societal Engagement** Facility operators, depending on national regulations and/or stakeholder requirements, may be required to establish monitoring strategies and integrate those plans into early licensing design developments. Although technologies exist, operational experience requires maturation for DGRs. The outputs of R&D on monitoring techniques and data treatment could be useful for individual national programmes when engaging with Civil Society and when planning for the operation and closure of a disposal facility. It is noted that decision making processes in a national context is out of the scope of Joint Programming.
5.5.3 Retrievability	**Improved understanding of waste package durability and disposal facility infrastructure with respect to retrievability.**	**KM, Innovation for Optimisation, Implementation Safety, Societal Engagement**

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Expected outcomes and impact: To improve understanding of the durability of waste packages ensuring their ability to be handled, durability of structures ensuring the maintenance of functional free play, removal operations performed without jeopardising safety, and the aptitude for dismantling of partial closure components (for cells and drifts) and for re-equipping the facility. Cooperation and relevant past projects: EC ESDRED project Reversibility: To develop a common position across Europe, and to exchange good practices (J3.17).	Tests and operational experience to demonstrate ease of retrieval or re-equipping of closed disposal areas is limited to a few advanced programmes and specific waste packages. For organisations that have a requirement to design for, and/ or evaluate, ease of retrieval or reversibility, work could also be driven by societal engagement. Future possible changes in stakeholder demands should be considered and scenarios anticipated.

5.7 SRA Theme 6: Siting and Licensing

Roadmap Theme Overview 6 provides background context and summarises existing knowledge in relation to the goal of demonstrating to regulators (and other stakeholders, incl. the public) that a properly sited disposal facility will protect people and the environment at the time of disposal and in the very long term, following closure. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 6.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
6.1 Site selection process and site screening		
6.1.1 Conceptual planning	No SRA activities identified	
6.1.2 Area survey and site screening	**NEW: Sharing information between different national programmes between siting activities** Expected outcome and impact: Improved access to experienced know-how and data (or from site-specific URLs, drilling campaigns in the framework of other projects like underground gas storage or deep geothermal energy). Including development of a (centralised?) environmental specimen bank. Cooperation and relevant past projects: IAEA Guidance on Siting	**KM** Siting programmes for implementation of a DGR require a specialised work force and a strong integration of collected data using cross-functional teams. Sharing of good practice and of collected data would help other programmes to progress, by building on existing approaches, especially on how to organise, structure and visualise data.
6.2 Site investigation and confirmation		
6.2.1 Site investigations	No SRA activities identified	
6.2.2 Detailed site characterisation and site confirmation	**Maintaining and developing understanding of tools and techniques for developing site descriptive models, including treatment of uncertainty management for site data** Expected outcomes and impact: To ensure that state-of-the-art techniques needed to interpret and model site characterisation information are available or can be made available in a timely manner to support site investigation activities. To ensure the skills and competencies are diffused to new generations (especially in the countries with a less-advanced program), to favour inclusion of young scientists in the context of geological studies supporting radioactive waste management and disposal. Cooperation and relevant past projects: EURAD	**KM** Site characterisation and establishing a conceptual descriptive model is a highly complex activity which every programme must undertake individually. Shared experience across programmes would help to foster spread of knowledge on latest advancements and maintenance of skill in this high specialised field. Knowledge management could be further improved by transfer of competencies and experiences to the new generations.

	Developing state-of-the-art on the methods of uncertainty management associated with site characteristics. Expected outcomes and impact: Identification, characterisation and management of uncertainties related to site characteristics, including possible geodynamics and tectonic perturbations of the site in the long-term. Understanding of how the uncertainties propagate through the site characterisation. Evaluation of the best way to communicate information about geologic uncertainties to the stakeholders. Cooperation and relevant past projects: EURAD-1.	**KM and Societal Engagement** Management of conceptual uncertainties in space and time, associated with site characteristics, with their limited knowledge and unreliable previsions, are needed for a transparent safety case. Way of communication uncertainties about site geology, its evolution and its future performance is fundamental for the public acceptance of the disposal program and to ease collaboration with regulator bodies. Engaging with CS about the management of uncertainties allow to build / maintain trust.
6.3 Permits and licensing		
6.3.1 Local land use planning	No SRA activities identified	
6.3.2 Regulatory licensing	No SRA activities identified	

5.8 SRA Theme 7: Safety case

Roadmap Theme Overview 7 provides background context and summarises existing knowledge in relation to the goal of Iteratively quantify and demonstrate, the safety of the disposal system and inform strategic design decisions. The table below characterises RD&D, strategic studies or knowledge management activities that have been identified by the EURAD SRA 2023 within Theme 7.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
7.1 Safety strategy		
7.1.1 Safety requirements	No SRA activities identified.	
7.1.2 Performance indicators	**NEW: Shared experience in the use of natural analogues.** Expected outcomes and impact: To verify and build confidence in long-term, large-scale processes. Cooperation and relevant past projects: The Cigar Lake analogue project, The CLAYTRAC Project.	**KM and Societal Engagement** Natural analogues are an inherent part of the multiple lines of reasoning strategy within the safety case. The period of time considered is so vast that natural and anthropogenic analogues are the only source of data at relevant timescales. Collaboratively developed use of natural analogues will reduce uncertainties, e.g., associated to extraction and interpretation of data. Sensitivity analyses and information from natural analogues can be used to enhance confidence in the safety case.
7.2 Integration of safety-related information		
7.2.1 Safety case production	**NEW: Digitisation of the Safety Case** Expected outcomes and impact: Improved use of interactive infographics, video (or other media), and the use of multiple output channels (e.g. pdf, e-books or web publishing) to improve the presentation of information and communication, either within the radioactive waste management organisation itself or to other stakeholders. Better use of resolvable hyperlinks, and full-text or link search capability to improve usability (including in the review process) and reduce repetition of information within Safety Case sections. Improved glossaries and controlled vocabularies for terms (or metadata) used in the safety case, allowing consistency and enrichment of existing information, while potentially aiding machine-readability, thereby facilitating the long-term management, storage and archiving of the Safety Case and the information contained within. Improved workflow processes and electronic signing to increase auditability and timeliness of information sharing and efficiency.	**KM** Digitisation of the safety case has the potential to guide safety case productions as well as to manage and to communicate knowledge to various audiences.

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	Cooperation and relevant past projects: NEA Digitisation of the Safety Case Workshop 2022	
7.2.2 Information, data, and knowledge management	**NEW: Management of knowledge (know how, know why, tacit knowledge) over the decades of repository development and Safety Case evolution** Expected outcomes and impact: Improved sharing of good practice and guidance on how to holistically develop and maintain a knowledge management and information management system (including how to implement integrated code frameworks). Applying excellence in data management will be a prerequisite for future successful development and advancement of artificial intelligence and digital twin use in the field of RWM, e.g., data harmonisation. Cooperation and relevant past projects: NEA IGSC IDKM Working Party.	**KM** All programmes are required to maintain and develop a competent workforce that requires continuous efforts to ensure that knowledge is transferred between generations during the long-time scales involved during the preparation of safety cases and their update once licensing has been achieved. This not only relates to the capability of an organisation to develop a safety and evaluate safety but applies to all competence necessary to implement a DGR.
7.3 Safety assessment and tools		
7.3.1 Performance assessment and system models	**Improved understanding and models for the impact of THMCB on the behaviour of the host rock and the buffer materials, including upscaling to link bottom-up and top-down approaches in performance assessments** Expected outcomes and impact: To further understand the impact of THMC on the behaviour of the host rock and the buffer materials, and to develop appropriate models coupling all the relevant phenomenology impacting the key processes during the transition from the non-saturated period to saturation following closure. Further development of reactive transport and coupled models to include THM-C/B interactions providing more fully coupled understanding and models that can capture transient processes (like desaturation stages, pore clogging, etc.). To extend deterministic and/or stochastic approaches to take into account the upscaling aspects regarding THM parameters. To extend up-scaling to the materials involved in radioactive waste disposal, e.g., cementitious-based materials, to develop multi-scale approaches for coupled processes (including chemistry, mechanics, hydraulic, etc.) and to develop multi-scale strategies to represent complex phenomena (redox processes, microbiology, mineral transformation, etc.). Cooperation and relevant past projects: EC project BENCHPAR, HE (Heater Experiment). EURAD-1 DONUT and ACED WP	**KM, Scientific Insight and Societal Engagement** Complex multi-physics/chemical models are required to enhance confidence in assumed performance assessment assumptions and parameters.
	Improved safety and performance assessment tools and computing Expected outcomes and impact: Improved mathematical methods to analyse the importance of physical properties defined as input of a simulation on the relevant output of	**KM, Innovation for Optimisation, Implementation Safety and Societal Engagement**

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	the simulation (sensitivity analysis), and to quantify the effect of uncertainties on these outputs (uncertainty analysis). To enable the use of numerical and highly parallelised code on a heterogeneous grid or cluster, to represent hydraulic and solute transfer in huge integrated systems (disposal and geological media), two-phase flow and transfer at the system level, reactive transport at the scale of many components, and THM couplings at a large scale. Interest in developing the use of more sophisticated codes, incl. machine learning and AI tools to push computational limits. There is also interest in exchanging about how to evaluate results coming from Supercomputing and Artificial Intelligence - Digital Twins (e.g. no access to baseline data). The fundamental question of the data format (either a common format or at least a standardised exchange format) needs to be addressed, given the potential mass of data that these new systems will produce. The development and application of digital/virtual twins is linked with several other topics of the SRA, e.g., monitoring strategies and management of monitoring results. Open-source performance assessment code development was included in the EURAD SRA 2019 and could also be considered as part of this broad need. E.g., to develop high performance computing-oriented code which can simulate multi-phase flow and transport in unsaturated porous media. Cooperation and relevant past projects: DECOVALEX	Required to enhance trust between all stakeholders in assumed performance assessment assumptions and parameters. Numerical models must be further improved concerning computational efficiency. Current computational models are often at a component scale and are not easily integrated and those which include detailed treatment of coupled processes are costly and take a long-time to run calculations. **Innovation for Optimisation** It is important to investigate how new technologies such as Digital twins and artificial intelligence may help to push the limits of existing safety assessment codes / models. Digital twins may help to achieve a better system understanding, which could be used for different categories of optimisation (safety, costs…). A common format for the data or for the exchange of data could be considered, in relation to the constraints of the systems hosting these data (database, models, measurements, etc.) **Societal Engagement** Digital / Virtual twins can be used as a tool to interact with CS, by having better "demonstrators'' of complex systems and enhance system understanding. It is also a tool to interact with CS about which parameters need to be monitored at which phases of a disposal programme.
	Develop methods and tools aiming to better justify the parametrisation of radionuclide migration in envelope/bounding scenarios in safety assessment Expected outcomes and impact: development of methods and tools allowing a better justification of envelope values (or distribution function) for parameters underlying radionuclide migration (Kd sorption, solubility limits, diffusion coefficients…). Database and phenomenon-based models are now well established for a large number of radionuclides for simplified (minerals) and real systems (rocks). Based on this knowledge new methods and tools will be developed for supporting the choice of robust range of parameter values (or distribution function) used in the Safety Case. Sensitivity and statistic approaches	**Implementation Safety** The treatment of envelope (bounding) scenarios constitutes an important part of the safety case. Envelope scenarios requires the selection of envelope values (or distribution function) for parameters underlying radionuclide migration (Kd sorption, solubility limits, diffusion coefficients…). The selection of envelope values (or distribution function) involves a lot of “expert judgement”. Development of methods and tools supporting a better justification of envelope values (or

Corresponding Roadmap Domains	Description of RD&D, Strategic Studies, or KM Needs of Common Interest	Drivers
	coupled to phenomenon-based models and existing database (sorption on pure phases and real rocks, thermodynamics database…) is expected to give new insights for the selection of envelope values.	distribution function) is expected to increase the robustness and reliability of the safety case (decrease the level of conservatism and gain margins).
7.3.2 Treatment of uncertainty	**Further refinement of methods to make sensitivity and uncertainty analyses** Expected outcomes and impact: Develop common approaches to demonstrate operational and post-closure safety and overall facility lifecycle evolution. Improved uncertainty treatment (models and data) using evolution scenarios (i.e., improved system representation during different timescales and for complex scenarios such as those involving multiple strongly coupled processes). Scalability analysis of tools for coupled processes. Cooperation and relevant past projects: EURAD-1	**KM, Scientific Insight and Societal Engagement** Required to enhance trust between all stakeholders in assumed performance assessment assumptions and parameters.
	NEW: Heterogeneity-induced dispersion in measured parameters and processes used in the description and prediction of repository systems for safety assessment. Expected outcomes and impact: To build on previous and ongoing empirical projects, where dispersion in data is routinely observed, but the underlying controls remain unclear. Core to this will be the detailed characterisation of material heterogeneity and its impact on THMCGB behaviour for both engineered barriers and host rock formations. To provide a modelling capability which can integrate available site data to account for heterogeneities in the near field. Cooperation and relevant past projects: FORGE, CEBAMA, BEACON, EURAD	**Implementation Safety, KM, Societal Engagement and Innovation for Optimisation** The ability to treat heterogeneity in detailed component models is often difficult due to the large datasets required and improved knowledge on key controls for some of the underlying processes. To support the development of digital twins, improved treatment of such processes could help to advance the capability of such models for use in more complex systems.
7.3.3 Scenario development and FEP analysis	No SRA activities are identified.	

6. Implementation of the EURAD SRA 2023

The EURAD SRA 2023 (D1.9) is a formal deliverable of the EURAD Joint Programme. It has been developed towards the end of EURAD-1 (2019-2024) and thus no significant changes are expected to impact its applicability for directing and guiding future cooperation activities in the field of Radioactive Waste Management within EC Joint Programming (or future Joint Partnerships) beyond 2024.

The EURAD SRA 2023 should be seen as a flexible output of EURAD and one of several tools that can support the initiation of future cooperation activities. Drivers used to characterise the identified needs in this SRA provide a link from the knowledge gap to the strategic need for progressing the work. They should thus provide guidance on the primary customers and end users to who the specification of any further work should be directed.

The scope of the EURAD SRA 2023 is broad and it is not expected that all needs identified should or could be addressed in a future Joint Programme (for example, EURAD-2). Rather it is recognised that some needs may already be in stages of development, being worked on by one or more national programmes and/or being established as pipeline projects within IAEA, NEA or other RWM cooperation projects.

Through a process of community engagement in 2023, and the establishment of proposal ideas between subject matter experts, end users and co-funders, it is anticipated that a sub-set of domains will be addressed through future Joint Programming. It is anticipated that to develop specific project ideas, the EURAD platform can enhance interpersonal exchange between the different Colleges.

References and Links

1 Scientific and Technical Basis for the Geological Disposal of Radioactive Wastes, IAEA Technical Reports Series No. 413 (2003). https://www-pub.iaea.org/MTCD/Publications/PDF/TRS413_web.pdf

2 Council Directive 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste (2011). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32011L0070&from=DA

3 Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects, Second Report {SWD(2019) 435 final} - {SWD(2019) 436 final}.
https://eur-lex.europa.eu/legal-content/EN/TXT/%20PDF/?uri=CELEX:52019DC0632&from=EN

4 EURAD SRA (2019)
https://www.ejp-eurad.eu/sites/default/files/2020-01/2._eurad_sra.pdf

5 EURAD Vision (2019)
https://www.ejp-eurad.eu/sites/default/files/2019-12/EURAD%20Vision.pdf

6 PREDIS Baseline SRA (2021)
https://predis-h2020.eu/wp-content/uploads/2021/08/PREDIS-T2.2_Baseline-SRA_M2.3_August-2021.pdf),

7 PREDIS Updated SRA (2023)
(Due April 2023) https://predis-h2020.eu/publications-and-reports/

8 EURAD Deployment Plan (2019)
https://www.ejp-eurad.eu/sites/default/files/2020-01/4.%20EURAD%20Deployment%20Plan.pdf

9 EURAD Roadmap (2021)
https://www.ejp-eurad.eu/roadmap

10 EURAD Knowledge Management and Networking Programme (2021)
https://www.ejp-eurad.eu/sites/default/files/2022-04/EURAD%20Knowledge%20Management%20and%20Networking%20Programme.pdf

11 EURAD D1.8 SRA Update Process (2020)
https://www.ejp-eurad.eu/publications/eurad-d18-process-extensive-update-eurad-sra