This draft document is issued by **ANDRA**, on behalf of the Core Group. It should be understood that the Core Group members are acting on a voluntary basis (i.e. on their own resources) as a **catalyst** and **facilitator** in the EURAD **proposal development phase until its submission** to the EC in September 2018. Once accepted, the governance structures as defined in the proposal will start applying.

Aim of this document: This document is the first issue of the Vision, Strategic Research Agenda (SRA), Roadmap, Implementation Plan and Governance Scheme that will be submitted with the EURAD first phase proposal to the EC in September 2018. It builds on the work of the EC JOPRAD project and good practice from other successful European Joint Programmes. The Founding Documents will only be formally issued/made available publicly if the EURAD is successfully launched and supported by the EC, therefore they are written in the future tense, in readiness for publication.

Endorsement of this document: All EURAD participants (i.e. all organisations that are named in the proposal) are reminded that through their participation in the Joint Programme, they endorse the Vision and positively support the content and implementation of the EURAD Founding Documents. It is not anticipated that a formal/signed declaration will be made to confirm endorsement, rather this is "de facto" through Mandated Actors (and their 3rd Parties) participation in the EURAD.

Timescales for development, review and endorsement:

- January 2018 – Table of Contents circulated to Core Group for approval - Completed
- 12th March 2018 – 1st Draft issued to Prof A. Hooper, P. Zuidema and ANDRA for initial review and update - Completed
- 30th March 2018 – Draft issued to Core Group representatives - Completed
- 7th May 2018 - 1st Preliminary Version Prepared and Issued to EURAD Community
- July 2018 – Approval
- September 2018 – Final Version Issued to EC with Proposal and Endorsed via Mandated Actors (and their 3rd Parties) participation in the EURAD

Vision, Strategic Research Agenda (SRA), Roadmap, Implementation Plan and Governance Scheme: European Joint Programme on Radioactive Waste Management (EURAD)

FINAL 24th September 2018

(Issue 1)

THIS PAGE IS INTENTIONALLY LEFT BLANK

FOREWORD 5

MANDATED ORGANISATIONS 7

EXECUTIVE SUMMARY 9

1. Background, Vision and Objectives of the Joint Programme 9
2. Contributors and Participants 10
3. Scientific Themes & Activities of Common Interest 11
4. Initial 5 Year Deployment Plan 14
5. Summary 14

GLOSSARY 16

1. INTRODUCTION 18

1.1. Successful RD&D collaboration across Europe 18
1.2. Status of European national radioactive waste management programmes 19
1.3. Contributors of European RD&D and participants of the EURAD 20
1.4. Remaining challenges of radioactive waste management 22
1.5. Overall scheme of the European joint programme on radioactive waste 22

2. EURAD - VISION 24

2.1. Our vision 24
2.2. Our goals 24
2.3. Joint Programme governing principles 24
2.4. Joint Programme scope and objectives 25
2.4.1. Develop, maintain and consolidate the scientific and technical basis of radioactive waste management (RWM) 25
2.4.2. Address important and complex issues and enable expert networking 26
2.4.3. Enhance knowledge management and transfer between organisations, Member States and generations 26
2.4.4. Interaction with Civil Society 27
2.5. Joint Programme expected impacts 27
2.5.1. How the Joint Programme will complement the National Programmes 27
2.6. Joint Programme Endorsement 28

3. EURAD – STRATEGIC RESEARCH AGENDA 28

Theme 1: Managing implementation and oversight of a radioactive waste management programme 31
Theme 2: Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal 34
Theme 3: Engineered barrier system (EBS) properties, function and long-term performance 41
Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution 46
Theme 5: Geological disposal facility design and the practicalities of implementation 51
Theme 6: Siting and licensing 56
Theme 7: Performance assessment, safety case development and safety analyses 59

4. EURAD - ROADMAP 66

5. EURAD – DEPLOYMENT PLAN 2019-2024 (EURAD 1) 76

5.1. Framework for the initial Deployment Plan 2019-2024 76
5.1.1. EURATOM WP2018 Call 76
5.1.2. H2020 European Joint Programme Cofund - Participation rules 76
5.1.3. H2020 European Joint Programme Cofund rate and form of grant 77
5.1.4. Eligible costs under H2020 European Joint Programme Cofund 77
5.2. Deployment mechanisms 77
5.2.1. RD&D Work Packages 77
5.2.2. Strategic Studies Work Packages 77
5.2.3. Knowledge Management Work Packages 78
5.2.4. Programme Management Office Work Package 78
5.2.5. Providing access to knowledge – cross cutting component 79
5.2.6. Interaction with Civil Society – cross cutting component 79
5.3. EURAD 1 – funding and cofunding mechanisms 82
5.3.1. Indicative distribution of EC funding between the different type of activities 82
5.3.2. Internal funding rates for each type of activity 83
5.3.3. Flexibility mechanisms 83
5.4. EURAD 1 - Work Packages 83
5.5. Update of the SRA/Roadmap during EURAD 1 84

6. EURAD – GOVERNANCE & EVALUATION 87

6.1. Governance 87
6.1.1. Conditions for Participation 89
6.2. Evaluation 89

Annex 1 – EURAD Terms of Reference 91

Annex 2 – Development of the EURAD Strategic Research Agenda 95

Annex 3 – Development of the EURAD Deployment Plan 2019-2024 101

Annex 4 – Supporting Documents & References 105

FOREWORD

All EU Member States generate radioactive waste, with national inventories ranging from single sources or small inventories, up to large and high activity inventories from those member states with extensive nuclear programmes, some of them including spent nuclear fuel or large stockpiles of nuclear material from reprocessing activities. Regardless of size they all have to manage radioactive waste safely in the long term. As some of the wastes will have a significant level of radioactivity for a very long time, many countries have decided to adopt the option of disposing of waste deep underground, a practice referred to as “geological disposal”. Deep geological disposal is recognised by participating Member countries of the NEA Radioactive Waste Management Committee (RWMC), as well as the European Commission and the IAEA, as the most safe and secure long-term solution, even though some countries wish to postpone implementation of disposal or to evaluate other options in parallel. Geological disposal of higher activity radioactive waste involves constructing an engineered facility, typically between 200 and 1,000 metres underground to isolate the wastes from the environment and to ensure the radioactivity is sufficiently contained so that it will not be released back to the surface (including surface groundwaters), in unacceptable amounts that may cause harm to humans and the environment.

Implementing disposal at a national level presents many technical, scientific, social, economic and environmental responsibilities, including a large research, development and demonstration (RD&D) effort required to understand overall safety and feasibility for the implementation of the required facilities, and to address the remaining challenges. In radioactive waste management, and especially in relation to disposal, the European Commission has been funding research and development for over 40 years, fostering what is today a strong cooperation between European laboratories, institutions and implementers. With Europe on the verge of operation of its first geological repositories for disposal of spent fuel and other long-lived radioactive wastes, a step-change in joint programming between Member States is timely to take advantage of the experience gathered by different Member States over the past decades. This also supports Member States in implementing the Council Directive (2011/70/Euratom) and the recently established common legal framework across Europe for the safe management of radioactive waste.

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), which includes disposal, has been

established to complement the national efforts and enables effective use of resources by fostering and strengthening RD&D collaboration. As of today, 52 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.

Building on the initial preparatory work of the EC JOPRAD project to identify remaining research priorities of common interest across Europe, the very first achievement of the EURAD has now been delivered by this document. This common Vision, Strategic Research Agenda (including Knowledge Management), Roadmap, Implementation Plan and Governance Scheme will guide cooperative research and investments in the field of radioactive waste management over the coming decades in Europe. The fruit of a tremendous amount of work and determination, this holistic, multi-generational and multi-disciplinary view is now a reality. This strategic approach will foster scientific capability and enhance the knowledge-base needed to implement the safe management, including disposal, of radioactive waste, promoting European research and delivering beneficial societal and economic impact for EU citizens.

Dr Jonathan Martin

Chair of IGD-TP

Dr Delphine Pellegrini

SITEX Network

Dr Christophe Bruggeman

Research Entity Network

MANDATED ORGANISATIONS

Country	Programme Owners	Mandated Actors/Beneficiaries	WMO	TSO	RE
Austria	Federal Ministry of Agriculture, Forestry, Environment and Water Management	**NES**	x		
Belgium	Ministre de la Sécurité et de l'Intérieur	**Bel V**		x	
	FPS Economy, SMEs, Self-Employed and Energy	**ONDRAF/NIRAS**	x		
	FPS Economy, SMEs, Self-Employed and Energy	**SCK-CEN**			x
Bulgaria	Ministry of Education and Science of Bulgaria	**TUS**			x
Cyprus	Ministry of Labour, welfare and social insurance	**University of Cyprus**			x
Czech Republic	State Office for Nuclear Safety	**SURO**		x	
	Minister of Education, Youth and Sports	**SURAO**	x		
	Minister of Education, Youth and Sports	**CV REZ**			x
Denmark	Ministry of Higher Education and Science	**Danish Decommissioning**	x		
Finland	Ministry of economic affairs and employment	**Posiva**	x		
		VTT		x	
		University of Helsinki			x
France	Ministère de la transition écologique et solidaire Ministère de l'Enseignement Supérieur et de la Recherche	**Andra**	x		
		IRSN		x	
		CNRS			x
		CEA			x
Germany	Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety Federal Ministry for Education and Research Federal Ministry for Economic Affairs an Energy	**BGE**	x		
		GRS		x	
		FZJ			x
		KIT-PTKA			x
Greece	Greek Atomic Energy Commission	**EEAE**	x		
		NCSR Demokritos			x
Hungary	Hungarian Ministry of National Development	**PURAM**	x		
		TS Enercon		x	
		MTA EK			x

Lithuania	Ministry of Energy	**IAE**	x		
		CPST		x	
		LEI			x
The Netherlands	Authority for Nuclear Safety and Radiation Protection	**COVRA**	x		
		NRG		x	
		TNO			x
Poland	Ministry of Energy	**RWMP**	x		
		INCT		x	
Portugal	COMRSIN	**IST**	x		
		IST-ID			x
Romania	Ministry of Energy	**RATEN ICN**			x
Slovenia	Slovenian Research Agency	**JSI**		x	
	Ministry of Infrastructure of Republic of Slovenia	**ARAO**	x		
Slovakia	Ministry of Education, Science, Research and Sport	**STUBA**			x
	Ministry of Education, Science, Research and Sport	**NJF**	x		
	Ministry of Education, Science, Research and Sport	**VUJE**		x	
Spain	Ministry of Energy, Tourism and Digital Agenda	**ENRESA**	x		
	Ministry of Economy Industry and Competitivity	**CIEMAT**		x	
Sweden	Nuclear Fuel and Waste Management Company, SKB	**SKB**	x		
United Kingdom	Department of Business, Energy and Industrial Strategy	**RWM**	x		
		BGS/NERC			x
Switzerland	Federal Department of Economic Affairs, Education and Research	**NAGRA**	x		
		PSI			x
Ukraine	State Agency of Ukraine on Exclusion Zone Management	**Chornobyl R&D Institute**	x		
		SSTC NRS		x	
		SSE "Ecocentre"			x
EC		**JRC**			x

EXECUTIVE SUMMARY

1. Background, Vision and Objectives of the Joint Programme

Following decades of research, development and demonstration (RD&D) in support of the safe management and disposal of radioactive waste, a European Joint Programme on Radioactive Waste Management (EURAD) has now been established to coordinate activities on agreed priorities of common interest between European Waste Management Organisations (WMOs), Technical Support Organisations (TSOs) and Research Entities (REs).

Such Joint Programming is meant to complement National RD&D Programmes, by founding and carrying out activities jointly 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.

The vision of the European Joint Programme on Radioactive Waste Management (EURAD) is:

> *"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".*

By step-change we mean a new era of more effective and efficient use of public RD&D funding in Europe, and a deepening of research-cooperation between Member States. We aim to implement a strategic Joint Programme of research and knowledge management activities at the European level, bringing together and complementing national EU Member State programmes in order to ensure cutting edge knowledge creation and preservation in view of delivering safe, sustainable and publicly acceptable solutions for the management of radioactive waste across Europe now and in the future.

The scope of the Joint Programme includes scientific and technical activities on radioactive waste management from cradle to grave (excluding dismantling and decommissioning of nuclear facilities):

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

The Joint Programme will generate and manage knowledge to support EU Member States with their implementation of the Waste Directive, taking into account the various differing stages of advancement of member state national programmes. This will encompass:

- Supporting 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; and

- Consolidating 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 optimization linked with the stepwise implementation of geological disposal.

From this, the Joint Programme has established the following high-level objectives:

- Develop, maintain and consolidate the scientific and technical basis of safe radioactive waste management;
- Address important and complex issues and enable expert networking;
- Enhance knowledge management and transfer between organisations, Member States and generations; and
- Engage with Civil Society.

2. Contributors and Participants

The Joint Programme contributors are those with scientific and technical responsibilities and a national mandate for research in radioactive waste management, including disposal. This includes:

- **Waste Management Organisations**

  With the 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 radioactive waste management (including waste characterisation, treatment, packaging and interim storage), waste management organisations (WMOs) across Europe form a core part of the Joint Programme. Providing the driving force for what is needed for successful and practical implementation from an industrial perspective, they are key contributors.

- **Technical Support Organisations**

  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 support organisations (TSOs). In that context, the regulatory expertise function, its RD&D interests and its independent participation in RD&D activities is promoted and included within the Joint Programme.

- **Research Entities**

  Providing scientific excellence and leading-edge research on basic components and generic processes in relation to the management of radioactive waste, research entities (REs) represent a large proportion of the contributions to the Joint Programme. Promoting the safe management of radioactive waste, research entities work to different degrees on the challenges of radioactive waste management including disposal (and sometime in direct support to implementers or WMOs or TSOs), under the responsibility of Member States. This includes national research centres, some research organisations and some universities that could also be funded by other sources. It also includes R&D departments of Waste Producer organisations.

The Joint Programme also includes observers and non-technical participants, who do not have a formal national mandate for research in radioactive waste management, including disposal, 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 radioactive waste management, including disposal. Within the Joint Programme, a group of representatives of the European Civil Society Organisations (CSOs) who are involved in

radioactive waste management activities at the EU or national level participate and interact with the JP. These interactions will be facilitated by Civil Society Experts.

- **Waste Producers**

  Waste Producers and those with a pre-disposal waste management remit are engaged via the Nuclear Generation II & III Association (NUGENIA). Although not direct contributors or participants of the Joint Programme, continued engagement via dissemination and consultation will ensure NUGENIA and their dedicated R&D on nuclear fission technologies and predisposal activities and, will set a foundation for future collaboration in projects influencing the wasteform for final disposal. Waste Producers and Waste Management Organisations /Implementers at a national level are often well-connected and have existing cooperation activities that should support the integration of Waste Producers RD&D needs (that impact disposal), via the WMOs. Waste Producers are often responsible for contributing to financing of disposal facilities.

- **International Organisations**

  It is recognised that the scientific basis and public acceptance of radioactive waste management solutions, including geological disposal, is a global effort, and that new opportunities may emerge to link to worldwide RD&D efforts. Already the Joint Programme has established close links with the International Atomic Energy Association (IAEA) from inception to avoid duplication of effort and resources. Such co-operation will continue, and extend to other organisations, including the Organisation for Economic Co-operation and Development – Nuclear Energy Agency (OECD-NEA), to strategically direct and offer clear added value to the Joint Programme objective.

- **Third Countries**

  Many past and ongoing EC projects have benefited from participation, exchange and cooperation with countries (or programmes) not a member of the Union. Defined as 'third countries' by the EC, it is anticipated that as the Joint Programme becomes established, such cooperation will continue and become firmly established.

3. Scientific Themes & Activities of Common Interest

The Strategic Research Agenda (SRA), developed during the Joint Programme preparation phase, provides a description of scientific and technical activities and knowledge management needs of common interest between the Joint Programme contributors and participants. These activities are grouped into a number of scientific themes and based upon the scope established by the EC JOPRAD Project:

- **Theme 1: Managing implementation and oversight of a radioactive waste management programme**

  Implementation of a national radioactive waste management programme, including geological disposal, requires a strong technical foundation of national policy to provide a legal framework, a long term vision, appropriate regulatory oversight, funding, organisational infrastructure and sound management systems and processes and frequent exchange among stakeholders. For

programmes in the early phase of establishing national policy or developing a waste management programme, there is international entities support (IAEA, NEA) and EU-wide good practice and lessons learned that can be used to facilitate implementation of suitable organisational structures and strategic decision making.

- **Theme 2: Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal.**

  This involves characterizing the various waste types (requiring activation calculations, evaluation of contamination carry-over, development of waste treatment and packing technology, etc.), evolution of waste matrix properties during extended interim storage times, developing waste acceptance criteria and developing model predictions about future waste. This also includes development of sufficient interim storage capacity. Source term and radionuclide release mechanisms need to be assessed for different waste forms/waste packages considering the interaction of the various interfaces with the disposal environment. In this broad area of work much information is already available or can be acquired through co-operation. Where remaining issues remain, they are often site and design specific.

- **Theme 3: Engineered barrier system properties, function and long-term performance.**

  Engineered barriers (overpack, buffer, backfill, seals, etc.) are in a broad sense comparable in many programmes and much basic information is already available today as there have been many European and international project to-date. Existing needs can be further developed through continued co-operation, which includes the provision of utilising available underground research laboratories to conduct large-scale demonstration and verification testing. However, at a national programme level some specific development work is often necessary to improve the understanding of the system of engineered barriers, optimise it or adapt it to the specific situation at hand. Remaining research issues concern in particular cementitious and to a lesser degree clay-based materials.

- **Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution.**

  Geoscience focussing on host rocks representative of the broad range of geologies to understand long-term geological evolution (and stability), and on the detailed understanding of the relevant properties and behaviour of different types of host rocks. This includes the transport properties of radionuclides and fluids, redox phenomena, coupled phenomena to address facility-induced disturbances, and the impact of gas). This also includes the demonstration and verification that the important coupled geomechanical, thermal, hydrological and chemical phenomena are sufficiently well understood to allow for long term assessment of void space closure, fluid movement and behaviour of the material interfaces, in some cases through full scale experiments in an Underground Research Laboratory (URL). The broad area of geoscience will require significant activities that are specific to each country (especially regional geology but also the details of specific rocks), but with respect to the properties of rocks, much can be learned from other programmes working on similar rocks and may involve co-operative projects in URLs.

- **Theme 5: Facility design and the practicalities of construction, operations and closure.**

Facility design (covering early conceptual design during early programme phases, right through to detailed design for construction, operation and closure). In the area of geomechanics and excavation, much can be learned from the tunnelling and mining industries and the corresponding science and technology developments. The current focus is on the demonstration of waste transport and engineered barrier emplacement techniques, and to perform demonstration tests under real 1:1 scale and active conditions. Underground research laboratories and/or rock characterisation facility experiments, incl. monitoring activities often focus on demonstrating that technical aspects of facility construction and operation are suited for their purpose.

- **Theme 6: Siting and licensing.**

  The selection of a site (or sites) and licensing for a geological disposal facility is clearly the most important challenge to the successful implementation of long-term management of radioactive wastes. Site characterisation (exploration of geometrical aspects, rock layers, structures, and characterisation of key rock properties), acquiring site parameters through the use of geophysical techniques, hydraulic, and geochemical and geophysical measurements in boreholes and seismic investigations will contribute to the selection of the preferred site. As part of the full development of the selected site, underground testing will be required to allow detailed in-situ confirmation (and/or refinement) of some of the critical data on rock properties and state parameters before and during the construction of the repository. Site selection policies and procedures, regulatory arrangements and licensing requirements vary between member states, reflecting inter alia the socio-political context, geological factors, and the waste inventory. In this broad area of work a large part is of national focus and much can be learned from science and technology e.g. developed for hydro-carbon exploration, but also the wealth of information available from radioactive waste management programmes and from previously existing URLs must be considered. For URL-experiments, significant technology developments have been made (testing tools, sensors, etc.) that are essential for underground testing at repository sites. This area is very much suited for co-operation.

- **Theme 7: Performance assessment, safety analyses and safety case development.**

  For safety analyses (methodology, numerical tools, compiling all the information and data, drawing the conclusions), a wealth of information is already available. The development of the safety case and the task of integrating all the necessary information will always be specific to the system evaluated and thus, in this area, each country must develop its own capabilities in interaction with the various local stakeholders, however, confidence building requires often international exchange and the help of experienced experts from elsewhere. Common issues include typically the exchange on the treatment of uncertainties. It is important to recognise the need for independence between those supporting and managing safety case development and those supporting or managing the regulatory review and scrutiny of a safety case, this applies to all the SRA Themes, but especially relevant to Theme 7.

The SRA is further complemented by a Roadmap that provides a framework to describe the totality of scope of the Joint Programme and its relevance to radioactive waste management (including disposal) programmes at different stages of maturity. The Roadmap effectively provides a framework upon which to organise the scientific and technical activities of the SRA, enabling programmes to ‘click-in’,

and to access active work or future plans. It also provides a framework for future periodic assessment of the Joint Programme, and to evaluate future priorities and new work packages as new knowledge is acquired or as new needs are identified.

4. Initial 5 Year Deployment Plan

A number of deployment activities will be needed to deliver the SRA and to refine the Roadmap for the initial 5 year period, recognising that there are a broad range of options that could be used. The Deployment Plan comprises a series of Work Packages, that each include elements of:

- **Collaborative RD&D**

  RD&D focused on science, engineering and technology advancements that support the generation of new knowledge to progress radioactive waste management, including disposal, across Europe. The activities to be carried out are a balance between operational / implementation-driven, safety-driven and prospective RD&D.

- **Strategic Studies to Address Important and Complex Issues and Enable Expert Networking**

  Strategic studies to agree upon needs for future activities, including further specific thematic studies or RD&D at the forefront of science. This may also be referred to as 'think-tank' activities and will enable experts and specialists to network on methodological/strategical issues and advance significant challenges that are common to various national programmes and that are in direct link with scientific and technical issues.

- **Knowledge Management**

  Actions consisting of establishing State-of-Knowledge and ensuring its transfer to end-users, developing descriptive methodological guidance, and developing and delivering training and mobility.

- **Interaction with Civil Society**

  Additionally, interaction activities with Civil Society will involve a group of representatives of Civil Society Organisations (CSOs) (including non-governmental organisations at local, national, European levels) willing to take part in the various work packages in the JP. These interactions will be facilitated by Civil Society Experts having a long-term engagement on RWM and/or having skills/experience on the involvement of civil society in scientific and technical issues.

The Deployment Plan is delivered in practical terms through the establishment of a clear governance scheme (and Joint Programme Terms of Reference), in addition to a dedicated Project Management Office that deals with the scientific and technical coordination of the overall programme, day-to-day administration and management, and communication and dissemination activities.

5. Summary

The European Joint Programme on Radioactive Waste Management (EURAD), which includes disposal, is a new and flexible mode of European research collaboration that has the capability to supplement and enhance national programme capabilities to address remaining scientific and technical challenges. This document sets out the common Vision of the 22 European countries involved and provides a strategic approach to support collaborative research and knowledge exchange that can exploit

emerging scientific opportunities and open scientific questions, and jointly support progress with respect to radioactive waste management, including disposal. The activities of common interest identified in the Strategic Research Agenda and Roadmap address a broad spectrum of research needs and drivers from programmes at all stages of implementation and recognise the important role that each stakeholder group has in delivering this agenda. This includes close interaction between experts from different backgrounds, organisations and perspectives to maintain a sustainable presence and openness on the underlying science and to reinforce the quality of the decision-making process for managing radioactive waste, including spent nuclear fuel. The ultimate goal is to undertake research, development and demonstration, technical strategic studies and enhance access to knowledge and management tools and infrastructure that aids national radioactive waste management programmes with their successful implementation.

GLOSSARY

Advanced Stage Programme	Radioactive waste management programmes that are close to implementation of disposal. This typically includes programmes that are licensing for construction, completing site-specific and detailed site characterisation, or programmes that have produced comprehensive safety cases (and their supporting evidence base) for detailed conceptual designs suitable for regulatory scrutiny and/or subject to international peer review.
CSO	Civil Society Organisation.
Early Stage Programme	Radioactive waste management programmes that are at an early stage of development with respect to implementing disposal. This typically includes programmes in establishment or undertaking preliminary site evaluation and selection, or programmes yet to develop demonstrable competence for producing comprehensive safety cases (and their supporting evidence base) for detailed conceptual designs.
Small Inventory Programme	Radioactive waste management programmes that have a small inventory typically containing medical waste, disused and sealed radioactive sources and possibly a small amount of spent nuclear fuel from research reactors. Such programmes typically consider the construction of a dedicated national geological repository unfeasible and work in pursuit of economical ways for disposing of small amounts of radioactive waste, either through the possibility of shared regional facilities, borehole disposal or through a focus on long-term storage.
EBS	Engineered Barrier System.
EC	European Commission.
EDZ	Excavation Disturbed Zone.
EURAD / JP	European Joint Programme on Radioactive Waste Programme / Joint Programme.
EURATOM	European Atomic Energy Community.
GDF	Geological Disposal Facility.
HLW	High Level Waste.
IAEA	International Atomic Energy Agency.
IGD-TP	Implementing Geological Disposal Technology Platform.
ILW	Intermediate Level Waste.
Licence	A legal document issued by the regulatory or governmental body granting authorization to perform specified activities related to a facility or activity. The holder of a current licence is termed a licensee. A licence is a product of the authorization process, although the term licensing process is sometimes used.
LLW	Low Level Waste.
NUGENIA	NUclear GENeration II & III Association.
RCF	A Rock Characterisation Facility excavated to the anticipated repository depth to give further information on the bedrock and groundwater conditions of the final disposal site, as well as on the impact of the construction (e.g. to

	investigate the rock at tunnel scale, to conduct in-situ testing, to develop excavation and final disposal techniques in realistic conditions).
RD&D	Research, Development and Demonstration.
RE	Research Entity.
RWM	Radioactive Waste Management (which includes predisposal activities and disposal)
Safety Case	An integrated collection of claims, supporting arguments and evidence to demonstrate the safety of a facility. This will normally include a safety assessment, but could also typically include information (including supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein. It may involve various stakeholders. The safety case evloves with the increase of maturity of the repository project.
SITEX Network	Sustainable network for Independent Technical Expertise of Radioactive Waste Management. The purpose of the SITEX Network is to enhance and foster cooperation at the international level in order to achieve a high quality Expertise Function in the field of safety of radioactive waste management (RWM), independent from organizations responsible for the implementation of waste management programs, aiming at supporting the Regulatory Authorities, as well as the Civil Society (CS).
SRA	Strategic Research Agenda.
TSO	Technical Support Organisation is a generic term referring to organisations fulfilling an “regulatory expertise function ”, i.e. carrying out activities aimed at providing the technical and scientific basis for supporting the decisions made by the national regulatory bodies.
URL	Underground Research Laboratory, may be built for in situ testing or tests may be carried out in an actual repository excavation. Such a facility allows to measure the full range of repository environment properties and waste repository system interactions be measured. Tests are conducted within a geological environment that is essentially equivalent to the environment of a potential geological disposal facility.
WMO	Waste Management Organisation.
Waste Processing	Any operation that changes the characteristics of waste, including pre-treatment, treatment and conditioning.

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, IAEA Scientific and Technical Basis for Near Surface Disposal of Low and Intermediate Level Waste) and geological disposal (see, IAEA Scientific and Technical Basis for the Geological Disposal of Radioactive Waste). This has supported countries to progress towards licensing of geological disposal facilities (e.g. Finland, Sweden and France) and contributed to the progress of numerous Member States' disposal programmes. RD&D efforts in radioactive waste management, including disposal, will continue to be necessary:

- 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 make this knowledge available to end users;
- To ensure optimisation of waste management routes and of disposal solutions;
- To address evolving regulatory concerns;
- 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.

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. More recently, the EC has also enhanced coordination and networking activities by supporting the establishment of the Implementing Geological Disposal 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 by regulatory authorities, regulators, and their technical support organisations (TSOs), which is also now independently funded.

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 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, 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 and a dedicated topic is included in the EURATOM WP2018 call that has been recently published (indicative EC available budget for 5 years: 26-32,5M€).

Link: http://ec.europa.eu/research/participants/data/ref/h2020/wp/2018-2020/euratom/h2020-wp1820-euratom_en.pdf

1.2. Status 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 policy 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 nuclear power (and fuel reprocessing) and defence 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 storage solutions and geological disposal.

Box 1: Illustration of the diversity of contexts within EU

In the EU, 16 Member States have a civil nuclear power programme.

12 Member States (Malta, Luxembourg, Cyprus, Croatia, Ireland, Greece, Portugal, Latvia, Estonia, Denmark, Austria and Poland) have no civil nuclear power programme.

Of these, 7 Member States (Portugal, Latvia, Estonia, Denmark, Austria, Greece and Poland) are operating or have operated research, training or demonstration reactors.

15 Member States have plans for geological disposal of intermediate level waste, high-level waste and spent fuel. Finland, France and Sweden are aiming at starting operation respectively by 2022, 2025 and 2030.

All Member States are at different phases of stepwise decision making in long-term radioactive waste management. A description of these phases, together with the collective experience of some Member States with advanced disposal programmes is given in IAEA - Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste.

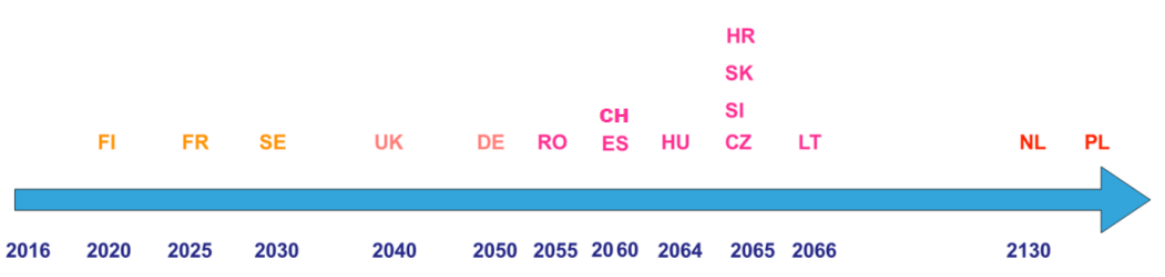


Figure 1- Planned start of operation of deep geological facilities (reproduced from: EC Progress Report on Progress of Implementation of Council Directive 2011/70/EURATOM)

Across Europe, the terms 'Advanced Stage Programme', 'Early Stage Programme' and 'Small Inventory Programme' are typically adopted (see Glossary for definitions). Regardless of size and stage of implementation, all Member States are responsible for the safe management of radioactive waste and are required to report periodically on the status of their national programme (See, Waste Directive).

The EURAD therefore includes:

- Member States with no nuclear power programme operating, or that have operated research, training or demonstration reactors, or other sources of radioactive waste;
- Member States with a nuclear programme;
- Member States with different amounts of radioactive waste to manage;
- Member States at different stages of advancement in the implementation of their national RWM programme; and
- Member States with plans for geological disposal for Spent Fuel, High-level Waste and long-lived intermediate level waste, with different disposal concepts and at different stages of implementation.

1.3. Contributors of European RD&D and participants of the EURAD

Across Europe, the organisation for how RD&D is managed and completed, 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 associated with the national programme.

Recent work (see, JOPRAD) identified three distinct categories of organisation, from across 28 EU Member States, Switzerland and Ukraine, with scientific and technical responsibilities and a national mandate for research in RWM, and that are willing to share a Strategic Research Agenda (SRA) for European collaborative RD&D:

- **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 the Joint Programme 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 needs of the implementers of geological disposal at the European level via the Implementing Geological Disposal Technology Platform (see, IGD-TP);

- **Technical Support 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 support

[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".

organisations (TSOs). Several TSOs, together with other organisations fulfilling a regulatory expertise function and CSOs have established the SITEX network to support independent technical expertise in the field of safety of geological disposal of radioactive waste; and

- **Research Entities** (REs) working to different degrees on the challenges of RWM including disposal (and sometime in direct support to implementers or WMOs or TSOs), under the responsibility of Member States. This includes national research centres, some research organisations and some universities that could also be funded by other sources. RE's provide scientific excellence 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 contributions to the Joint Programme.

The Joint Programme also includes observers and non-technical participants, who do not have a formal national mandate for research in RWM, including disposal, 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 the Joint Programme, a group of representatives of the European Civil Society Organisations (CSOs) who are involved in RWM activities at EU or national level interact with JP participants. These interactions will be facilitated by Civil Society Experts.

- **Waste Producers**

  Waste Producers and those with a pre-disposal waste management remit are engaged via the Nuclear Generation II & III Association (NUGENIA). Although not direct contributors or participants of the Joint Programme, continued engagement via dissemination and consultation will ensure NUGENIA and their dedicated R&D on nuclear fission technologies and predisposal activities, will set a foundation for future collaboration in projects influencing the wasteform for final disposal. Waste Producers and Waste Management Organisations /Implementers at a national level are often well-connected and have existing cooperation activities that should support the integration of Waste Producers RD&D needs (that impact disposal), via the WMOs. Waste Producers are often responsible for contributing to financing of disposal facilities.

- **International Organisations**

  It is recognised that the scientific basis and public acceptance of RWM solutions, including geological disposal, is a global effort, and that new opportunities may emerge to link to worldwide RD&D efforts. Already the Joint Programme has established close links with the International Atomic Energy Association (IAEA) from inception to avoid duplication of effort and resources. Such co-operation will continue, and extend to other organisations, including the Organisation for Economic Co-operation and Development – Nuclear Energy Agency (OECD-NEA), to strategically direct and offer clear added value to the Joint Programme objective.

- **Third Countries**

  Many past and ongoing EC projects have benefited from participation, exchange and cooperation with countries (or programmes) not a member of the Union. Defined as 'third countries' by the EC, it is anticipated that as the Joint Programme becomes established, such cooperation will continue and become firmly established.

1.4. Remaining challenges of radioactive waste management

The community involved in the management of radioactive waste and the development of a geological disposal facility will face several challenges over the coming years, each presenting its own scientific needs that will need to be addressed using a broad range of activities:

- The implementation of the first geological disposal facilities by the more advanced programmes;
- The harmonisation of practices fostered by European initiatives such as WENRA, Waste Directive, Nuclear Safety Directive, and Aarhus Convention, etc.;
- The development and update of early stage programmes to start a disposal siting and licensing process, taking benefit of the experience gained by advanced programmes;
- The establishment of the State-of-Knowledge and its transfer to end users;
- The availability of competencies, research infrastructures and programmes to accompany the implementation and contribute to optimizing the management, including the disposal, of radioactive waste; and
- The necessity of creating a multi-decennial research and knowledge management perspective, considering the more than 100 years process between siting, licensing, operation and closure of a typical geological disposal programme.

1.5. Overall scheme of the European joint programme on radioactive waste

The European Joint Programme on Radioactive Waste (EURAD) has been established in 2019, following a period of preparation to establish a common Vision, Strategic Research Agenda, Roadmap, Implementation Plan, and Governance Scheme, building on the work completed by the EC project JOPRAD). Together these documents comprise the EURAD Founding Documents. Figure 2 below illustrates how the Founding Documents fit into the overall scheme of the EURAD.

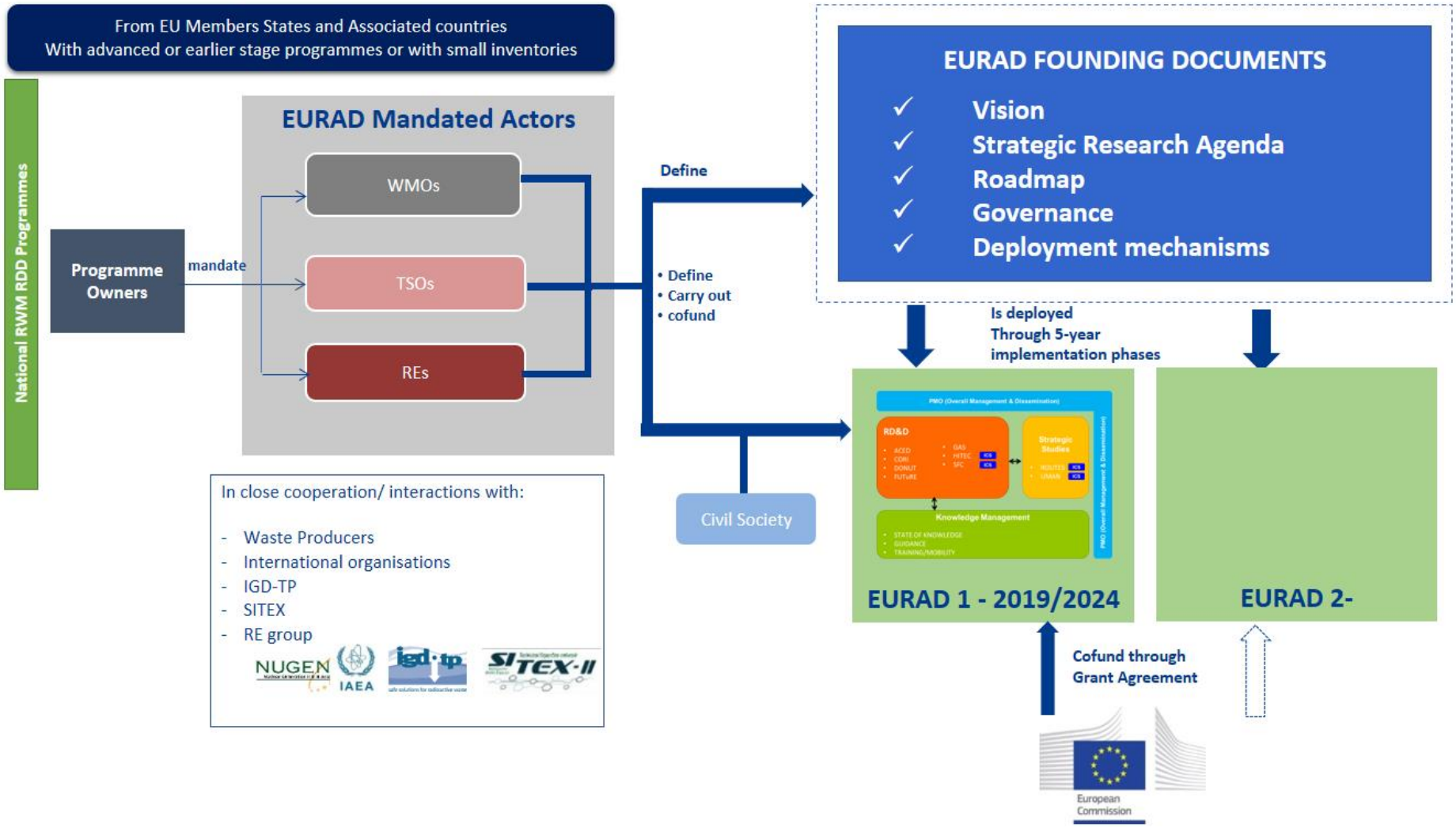


Figure 2. Overall scheme of the European Joint Programme on Radioactive Waste (EURAD)

2. EURAD - VISION

2.1. Our 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.

By step-change we mean a new era via a more effective and efficient public RD&D funding in Europe, and a deepening of research-cooperation between Member States. The aim is to implement a joint Strategic Programme of research and knowledge management activities at the European level, bringing together and complementing EU Member State programmes in order to ensure cutting edge knowledge creation and preservation in view of delivering safe, sustainable and publicly acceptable solutions for the management of radioactive waste across Europe now and in the future.

2.2. Our goals

The Joint Programme 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 optimization linked with the stepwise implementation of geological disposal;
- Enhance knowledge management and transfer between organisations, Member States and generations.

2.3. Joint Programme governing principles

The Joint Programme shall respect the following principles:

- **Positive Participation –** Contributors will work positively towards achievement of the Joint Programme Vision. All contributions will be valued. Work will be carried out considerately and respectfully by all, maintaining relationships that respect diversity, different roles and boundaries, and respect the knowledge, insight, experience and expertise of others.
- **Maintenance of Independence** – It is possible for different organisations with different roles in their national programme to work together, without prejudice to their own role in the national implementation process. Most important is the independence between the “expertise function” (fulfilled by TSOs and by some Research Entities) and the “implementer function” (fulfilled by WMOs). Different parties (WMOs and TSOs in particular) can have common agreement of what RD&D should be done and how, and Research Entities have a long term vision of research needs. All can collaborate in the oversight of that research, however, developing their own views on the interpretation of the research results and data that are generated is essential;

- **Transparent Governance** – A transparent, balanced and efficient mode of governance, taking into account Joint Programme participants with a national mandate for research in radioactive waste management;
- **Scientific Excellence** – RD&D activities shall focus on achieving passive safety (safety of a disposal facility is provided for by means of passive features inherent in the characteristics of the site and the facility and the characteristics of the waste packages, together with certain institutional controls, particularly for surface facilities) and reducing uncertainties through excellence in science.
- **Balanced Programme** – Recognising that different Member States have a wide variance in the status of their National Programme, the scope should support programmes at all stages of advancement;
- **Added Value** – Ensuring that Joint Programming provides real added value (e.g. improved financial arrangements, improved stakeholder acceptance of outputs, more robust RD&D outputs, etc.). Administration costs should represent a small proportion (including ongoing legal, EC admin., etc.) versus money spent on the technical and scientific scope;
- **Inclusiveness** – Ensuring that the different categories of actors and groups of interest are involved in the definition and implementation of the Joint Programme;
- **Equitable Financing** – Financial costs (financial/in-kind) should be equitable; participants should contribute what they can afford, or what they consider matches their interest in a project;
- **Complementary Participation** – Participation in Joint Programme is complementary to RD&D activities which will continue to be undertaken nationally or jointly outside of the auspices of the Joint Programme where required; and
- **Tangible Results** – The scope is appropriately prioritised and focused on the objective to achieve tangible results within a reasonable timeframe. A key aspect is that participants recognise that the Joint Programme is a distinct change from past work (and other collaborative working) on radioactive waste management. Translating the societal challenge of radioactive waste management (including disposal) into operational reality requires the generation of new knowledge, combined with the consolidation, maintenance and transfer of existing knowledge.

2.4. Joint Programme scope and objectives

2.4.1. Develop, maintain and consolidate the scientific and technical basis of radioactive waste management (RWM)

The research, development and demonstration (RD&D) carried out in support of safe radioactive waste management (RWM), including disposal, is considered a key component of each national programme. Given the long timescales and socio-political dimension, RD&D provides primarily the scientific basis for implementing safe RWM solutions, whilst also contributing to building stakeholder trust, public acceptance, and training and education for generations of the workforce.

The Joint Programme consists of collaboratively developing, maintaining and consolidating at the European level the scientific and technical basis of RWM, including disposal.

The scope of the Joint Programme includes scientific and technical activities on RWM from cradle to grave:

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

Specific RD&D required for near-surface or surface disposal and low-level waste (LLW), will be addressed, and is encompassed within the RD&D needs identified for waste characterisation and processing, interim storage and geological disposal of radioactive waste. Nuclear facility dismantling and decommissioning activities are however excluded, although interfaces, and particularly aspects that impacts final disposal will be considered.

The Joint Programme scope is organised at a strategic level by 7 scientific themes. Each theme is further split into a list of topics and sub-topics (mostly collaborative RD&D, and relevant strategic studies or knowledge management activities), that in-part, or in-full, contribute to the overall European effort to address remaining challenges of RWM, including disposal.

The Joint Programme implements in a collaborative way those aspects of RD&D activities required within national research RWM programmes as well as associated activities where synergy from Joint Programming at European level has been identified. The prioritised scope identified is described more fully in the Strategic Research Agenda (SRA – see Section 3) and will support achievement of the Joint Programme Vision.

2.4.2. Address important and complex issues and enable expert networking

Complementary to RD&D and in support to the implementation of the Member States' national programmes, the Joint Programme shall give the opportunity to participants and expert contributors to network on methodological and strategic issues and challenges that are common to various national programmes and in direct links with scientific and technical issues:

- Share knowledge and discuss common methodological/strategical challenging issues (strategic studies) that are in close link with scientific, technical and societal aspects on RWM and that are common to various national programmes;
- Identify the contribution of past and on-going RD&D projects to the resolution of these issues;
- Identify any emerging topics for collaboration that could be addressed within the Joint Programme;
- Take into account emerging science and technology as well as research priorities originating from other programmes (for example results from Horizon 2020 projects or IAEA outputs).

2.4.3. Enhance knowledge management and transfer between organisations, Member States and generations

It is essential to implement an efficient and integrated Knowledge Management programme at the EU level in order to establish, capitalize and transfer the state of scientific and technical knowledge in the field of RWM. Objectives are to:

- Make sure that the publicly financed knowledge generated over the past, ongoing and future RD&D activities is preserved and made accessible.
  Preservation / capitalisation of generated knowledge

- Make sure that Member-States with national programmes at an early-stage of implementation can take advantage of existing knowledge and know-how from the Member-States with advanced national programmes, primarily to access state of the art, and second to ease access to knowledge developed during previous EC supported RD&D projects.
  Transfer of knowledge towards Member-States with early-stage RWM programmes

- Ensure that the necessary expertise and skills are maintained through generations of experts in view of the long lead-times and operational time-spans (several decades) for RWM, including disposal, by providing training and mobility for researchers.
  Transfer of knowledge between generations

- Disseminate and demonstrate progress, results and added-value of the European Joint Programme to a wider audience.
  Dissemination of knowledge

2.4.4. Interaction with Civil Society

The successful implementation of RWM programmes relies on both scientific and technical aspects for a sound safety strategy and scientific and engineering excellence and societal (social, legal, ethical, political) aspects.

Civil Society organisations are not research organisations but have a specific concern on RWM safety and are involved in the perspective of the implementation of the UNECE Aarhus Convention which reinforces the requirements of access to information, public participation in decision-making and access to justice in environmental matters (See Annex 4, Aarhus Convention). European programmes therefore undertake work to address these requirements through local and national stakeholder engagement activities to enable Civil Society (representative organisations, e.g. Non-Government Organizations, Local Community Partnerships, etc.) to participate in defining their national RD&D programmes and the evaluation of RD&D results in the perspective of safety.

Interacting with Civil Society is important in this perspective and therefore one objective of the Joint Programme is to allow interactions between WMOs, TSOs and REs, Civil Society Organisations (CSOs). These interactions will facilitate the translation of scientific/technical results and create the conditions for Civil Society Organisations to interpret, discuss on the technical progress (and results), and express their expectations or views. Such interactions shall improve the mutual understanding of how and to what extent an RD&D activity on RWM makes sense and contributes to improving decisions. It shall also contribute to developing ideas, propositions and methodologies on how to interact with Civil Society on scientific and technical results, how to deal with uncertainties (inherently linked to the long timeframes and numerous processes considered for geological disposal), and on how to interact with Civil Society stakeholders in order to promote mutual benefit of the available knowledge, based on cooperation and sharing.

2.5. Joint Programme expected impacts

2.5.1. How the Joint Programme will complement the National Programmes

The Joint Programme is not intended to replace National Programmes, rather it complements the national efforts and enables effective use of resources by sharing RD&D efforts and by making existing knowledge easily available to end users. Member States' National Programmes are organised and

funded independently, and their participation in the Joint Programme is the responsibility, and at the sole discretion, of each national programme owner. By mandating organisations to participate, Member States demonstrate that the European Joint Programme has an EU-added value beyond their National Programme. Overall the following Joint programme impacts can be expected:

1. **Support compliance with European regulations** – by supporting Member States in implementing RD&D, developing skills and providing for transparency in order to develop solutions for their radioactive waste (see, Waste Directive articles 8, 10 and 12.1(f));
2. **Support passive safety of radioactive waste** – by contributing to the responsible and safe management of radioactive waste in Europe, including the safe start of operation of the first geological disposal facilities for high-level and long-lived radioactive waste / spent nuclear fuel as well as improvement, innovation and development of science and technology for the management and disposal of other radioactive waste categories;
3. **Help to gain or maintain public confidence and awareness in radioactive waste management** - by fostering transparency, credibility and scientific excellence;
4. **Support radioactive waste management innovation and optimisation** – by supporting the development of solutions for different waste streams and types and continuously improving and optimising waste management routes and disposal solutions, including identifying needs specific to small inventory programmes with their particular challenges with respect to access to critical mass of expertise and developing appropriate disposal options;
5. **Contribute to addressing scientific/technical challenges and evolving regulatory concerns** – by prioritising activities of high common interest, and creating conditions for cross fertilization, interaction and mutual understanding between different Joint Programme contributors and participants;
6. **Enhance knowledge transfer to early stage programmes** – by providing an opportunity for less advanced programmes, and in particular those in an early stage of geological disposal programme implementation, to benefit from the cross-European integration in radioactive waste management;
7. **Foster efficient use of the RD&D resources at the EU level** - by sharing and advancing existing knowledge, facilities and infrastructure rather than repeating and duplicating efforts; and
8. **Foster a better transfer of knowledge across generations of experts** – by helping to bridge the risk of shortage of the skilled, multidisciplinary human resources and critical infrastructure needed to develop, assess, license and operate RWM facilities, in view of the long lead-times and the intergenerational operational time-spans.

2.6. Joint Programme Endorsement

All Joint Programme participants, through their participation in the Joint Programme, endorse the Vision and positively support the content and implementation of the EURAD Founding Documents.

3. EURAD – STRATEGIC RESEARCH AGENDA

The Strategic Research Agenda (SRA) of the Joint Programme has been developed in a stage-wise manner, Step 1 - taking over entirely the scope developed within the EC JOPRAD Project (See, D4.2 Programme Document), and Step 2 – enhanced with a small number of additional needs identified by ongoing EC projects and approved for inclusion between the key contributors of the JP. The detailed methodology used for both of these steps is described fully in Annex 2.

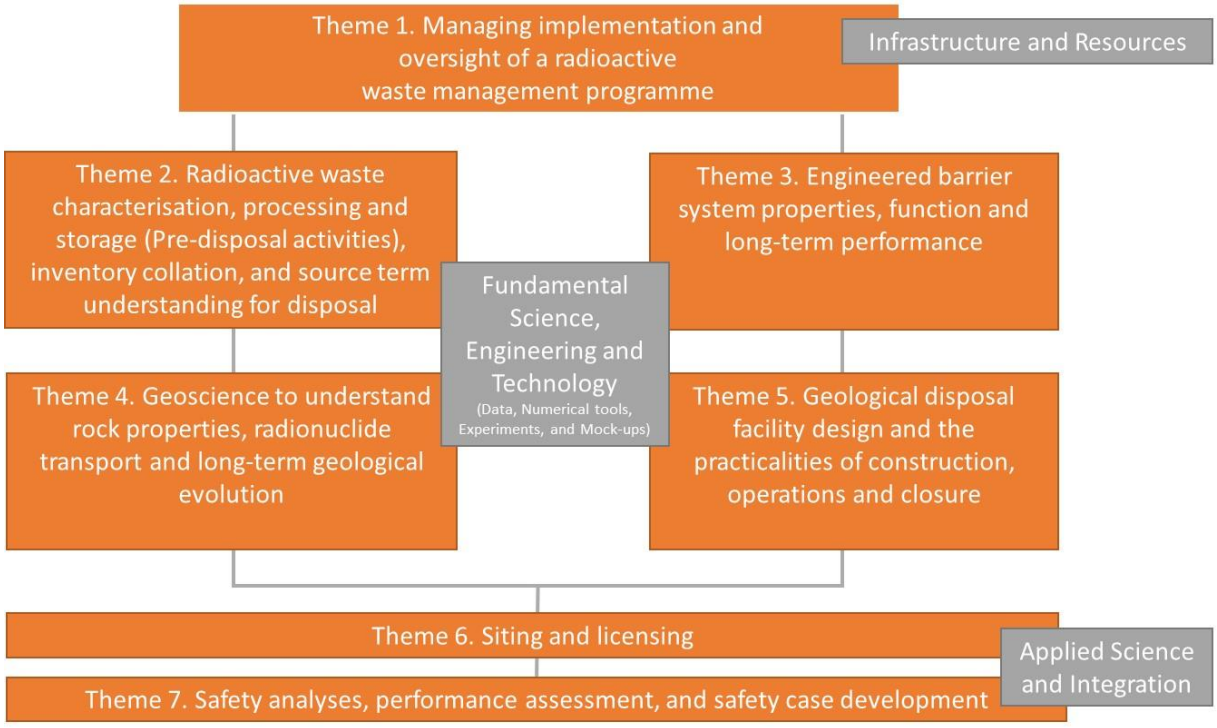
The Strategic Research Agenda (SRA) will be a dynamic and living document that shall be updated periodically in order to integrate outcomes of RD&D activities as well as any emerging collaboration needs identified by the RWM community during the implementation phases of the Joint Programme.

We anticipate that there will be regular 'soft' updates to make minor edits and additions. This will be complemented by periodic extensive updates to coincide with future Work Package developments (for example during identification and prioritisation of EURAD 2 scope) where it is anticipated that significant changes may result to take account of learning from EURAD 1 and align the SRA, Roadmap and Work Package scope and methodologies with how things evolve, particularly with respect to the JP governance scheme and how the criteria used to identify needs of the WMOs, TSOs and REs.

In its current form, together with the Roadmap in Section 5, it should be considered a first version, and be open to changes in structure, content, scope, titles, and new numbering in the future, particularly to account for maturity of the Joint Programme and evolution of different Programmes' needs. It is anticipated that new scope suggestions and/or edits will be made in consultation with the Joint Programme participants in an open and transparent manner.

The SRA scope is structured by seven Scientific Themes, as illustrated in Figure 3. These themes are also used in the roadmap. Although all technical in nature, Theme 1 is an overarching theme, Themes 2-5 are predominantly focussed on fundamental science, engineering, and technology, and Themes 6 and 7 include aspects more of an applied science and integration focus.

Figure 3. Scientific Themes of the Joint Programme SRA

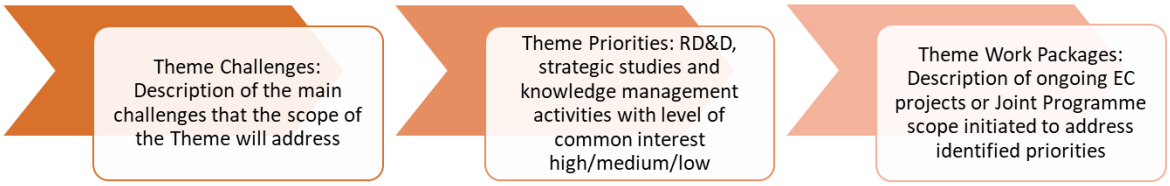


Within each theme, the SRA provides (i) a short introduction and background section, broken down into a number of topics that are further used in the roadmap. The SRA then provides (ii) a list of RD&D priorities, strategic studies and Knowledge Management activities of common interest to be addressed by the Joint Programme, using the tasks numbers from the EC JOPRAD project (in the future version a new numbering system shall be implemented). For each there is an indication of relevant cooperation and past EC projects that should be considered at the time of task initiation; and (iii) a summary of

ongoing and active work (including Horizon 2020 projects) that address in-part, or in-full, the activities and priorities identified for each Theme. This structure is further summarised by Figure 4 below.

An important consideration in developing the SRA themes, and their further delineation into topics and sub-topics, has been to avoid grouping scientific and technical scope according to rock type (e.g. clay, hard-rock, or salt systems) or by disposal concept and design (e.g. vertical borehole, horizontal tunnel or vaulted systems). Rather, the Joint Programme SRA considers integration of scope across programmes with varying rock types and concept designs as highly beneficial, resulting in enhanced cross-fertilisation between established communities of practice for specific areas of scientific and technical competence.

Figure 4. The Structure of the Joint Programme SRA



The Joint Programme SRA does not describe activities that are handled by individual Member States' RD&D programmes, and should not be considered an exhaustive list of all RD&D initiatives or active work within Europe. It only includes initiatives that are currently coordinated and funded by the EC and those that have been brought to the attention, and considered relevant for cooperative work, by Joint Programme participants. Recognising the potential overlaps with existing initiatives and the coordination needed to ensure that the Joint Programme delivers on its remit to provide European added value, for each RD&D activity, the SRA includes an indication of known opportunities for interaction. This will also be addressed within the knowledge management activities. (**Note that this activity has yet to be completed in coordination with IAEA*).

The SRA Tables of RD&D Priorities indicate the surveyed High, Medium or Low level of Common Interest, as identified by EC Project JOPRAD (see Annex II). The enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities identified of common interest (by JOPRAD) that relate to each Theme are included without an indication of High, Medium or Low level priority. It is anticipated that the first phase of JP implementation will address this by additionally surveying Member States needs on these aspects and developing a specific list of priorities as a basis for the future JP work, beyond the collaborative RD&D scope.

Theme 1: Managing implementation and oversight of a radioactive waste management programme

Programme planning

Radioactive waste management (RWM) programmes present special challenges in their planning and execution, for which on-going programmes have already lasted for several decades. They involve not only significant science, technology and engineering but also substantial elements of programme management, regulation, politics, financing, resourcing, and most importantly, public participation and stakeholder engagement. Such elements are included in the Waste Directive and elaborated further in the ENEF NAPRO Guide (see Annex 4). International collaboration on these aspects hold many advantages for both early-stage programmes and advanced programmes, and although not considered pure RD&D, they require expert technical knowledge, sharing of good practice, and hence are included within the Joint Programme scope.

Establishing very early on a national programme with decision milestones, and clear roles and responsibilities, enables all parties (i.e. government, regulator, operator and public) to commit to progress. Particularly when implementing geological disposal, public participation and stakeholder involvement has great importance to the planning of the programme. Lessons learned from past programme experiences show that engineering aspects tend to be well understood, with sufficient experience to accurately plan the effort and resources required. In contrast, the scientific effort (site characterisation, process modelling, safety assessment etc.), while already providing understanding of process understanding and impacts on safety, is evolving over time leading to new view points and sometimes new uncertainties and it is less predictable in the outcome, duration or resources that may eventually be required. Accounting for such uncertainty has become a key part of successful programme planning, and would benefit from continued sharing of methodologies and experience.

A clear strategy and commitment to involvement of stakeholders is essential to the decision-making process at all stages of a waste management programme. This will include how stakeholders with interest in RD&D will be involved and ways of communicating the scientific basis of waste management solutions for a range of audiences, including those for disposal. Throughout the preparatory work of the Joint Programme (see, the EC JOPRAD project), experts of Civil Society have contributed to and influenced the scope of work to be addressed.

Organisation

All programmes benefit from an established waste management and disposal policy and regulatory framework established prior to the initiation of substantial site work. These should be clear, comprehensive and in line with accepted principles promulgated internationally. It is essential that those working in direct support of the national regulatory bodies continue to network and harmonise views on how to develop, maintain and apply regulations.

The Waste Directive requires Members States to ensure they have National Programmes leading to implementation of safe and responsible management of spent fuel and radioactive waste. This includes the requirement to each develop a dedicated RD&D programme and transparent policy, see Waste Directive Articles 12 (1,F) and 12(1,J). Member States completed their first notification to the Waste Directive in 2015,

however their responses have not been made available or used directly to determine the scope of the Joint Programme. Rather, Member States with this responsibility are able to influence the Joint Programme scope through their participation. Inputs from early-stage programmes have already been included into the Joint Programme by earlier work undertaken by the Implementing Geological Disposal Technology Platform (IGD-TP) which prepared a preliminary Guide on RD&D programme planning for geological disposal in 2015, the PLANDIS Guide. Aimed at early-stage programmes, it suggested a number of activities that would benefit from further guidance, anticipated to be developed within the Joint Programme Knowledge Management Scope.

Resources

In the perspective of decades-long programme management, organisational capabilities related to resources (competence maintenance, education and training), financing (forecasting and costing), and the adoption of sound management systems and processes are all needed.

Across Europe there are a large number of organisations within many countries with resources (databases, equipment, capabilities, etc.) relating to the management and disposal of radioactive waste. Further networking and documentation of such infrastructure could aid early-stage programmes to tap into an existing talent pool and also help advanced programmes manage emerging skill gaps either for new competencies identified, or to manage capacity when key individuals have retired or local/national resources are unavailable. Sharing of competence matrices for different roles (regulator versus implementor) and how these evolve through successive phases of a waste management programme would be highly advantageous.

Information management, record keeping and maintaining memory are important activities within the context of implementing geological disposal (and long-term waste storage). The IAEA and OECD-NEA are involved in providing guidance in support of those aspects. The outcome of their work is transferred through participation in project activities establishing the guidance and recommendations, as well as through dissemination of the outcomes through conferences, proceedings and guides.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[2]:

Theme 1: Managing implementation and oversight of a radioactive waste management programme	• **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 (J3.15/High). - Expected outcomes and impact: Improved understanding of the breadth and depth of research infrastructure across Europe. - Cooperation and relevant past projects: possibility to explore training / mobility exchange at some sites / URLs
	• **Pre-licensing management:** To identify RD&D and knowledge transfer needs in support of defining pre-licensing activities that can support success in the siting and licensing phase/process (J3.11/Low).

[2] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

	- Expected outcomes and impact: Enable programmes to structure and prepare successfully for licensing. - Cooperation and relevant past projects: ?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 1: Managing implementation and oversight of a waste management programme.

How to establish and implement a radioactive waste management RD&D programme: To develop a common guidance document to support waste management programmes, including disposal, with establishment and implementation of a RD&D programme (Originates from needs identified by the IGD-TP PLANDIS Guide (See Annex 4).

- **Training and competence maintenance of skills and expertise to support safe radioactive waste management including disposal:** To ensure knowledge is managed and disseminated, and that there is competence maintenance, education and training of the workforce (J3.16).
- **Information management:** To maintain information, knowledge and records over the long lead- and implementation-timelines of geological disposal programmes, from pre-licensing through to the post-operational phase (J3.14/Medium).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 1:

As previously mentioned, the Member States responses to the Waste Directive, together with Member States responsibility towards the IAEA Joint Convention provide considerable inputs and enable access to networks, resources and experience for how to establish the key components of a RWM programme at a national strategic level.

Regarding training, the EC ANNETTE project (2016-2019) is consolidating existing achievements to tackle the challenges in ensuring a qualified nuclear workforce is available to support future nuclear energy, decommissioning and waste management requirements. ANNETTE aims to enhance European-wide efforts initiated in the past decades by different organisations belonging to academia, research centres and industry to maintain and develop education and training in the different nuclear areas. Links between ANNETTE and the Joint Programme Knowledge Management Work Package on Training are anticipated.

Within the JP first phase, it is anticipated that one of the first guidance documents to be produced will be on establishing and implementing a RWM RD&D programme, building on the work of the IGD-TP PLANDIS Guide.

Theme 2: Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal

Introduction and background:

Waste handling, characterisation, treatment and packaging

Sufficient knowledge of the waste characteristics is necessary to define suitable treatment and conditioning, both for passive safety and for final disposal. Spent Fuels and vitrified high-level wastes are generally well characterised. Remaining uncertainties include inventories of some long-lived beta emitting activation products like Cl36, C14 etc. Regarding long-lived intermediate level and low-level wastes, often, countries need to manage historical radioactive waste without adequate information about their origin and radionuclide content, and in some cases waste streams have been mixed. The problem may be more pronounced in countries having small amounts of radioactive waste which may not have the necessary funds to characterise the waste using available technology. Therefore, there is a need for developing reliable and affordable technologies for cost-effective characterization and segregation of historical preconditioned radioactive waste. Non-destructive assay techniques could enable the rapid characterisation of wastes prior to packaging, during storage, prior to dispatch to a GDF, or upon receipt at a GDF. These techniques could allow characterization of the gamma-radionuclide content, fissile content, physical and chemical characteristics of waste packages.

Significant progress has been made in the development of robust disposal concepts (including packaging options) for spent fuel, high-level wastes and many intermediate and low-level wastes. There is an opportunity for the identification of good practice between Member States where disposal concepts have been developed, however there is also a need to develop novel conditioning technologies for problematic wastes and further explore less-investigated waste conditioning options, such as geopolymers.

Interim storage

Radioactive waste may be transported and placed in interim storage prior to disposal covering a timespan of several decades up to a century or more. Unexpected delays in disposal programmes may extend storage periods beyond what was originally anticipated in the national programme. Therefore key considerations include degradation of the wasteforms and packaged waste during these relatively long or extended timespans, and the resulting impacts on the safety of the storage facility, as well as on the operational and post-closure safety of the geological disposal facility. Key considerations currently include waste package storage monitoring systems, aging and sealing of spent fuel storage casks, potential impacts of defects on spent fuel performance and re-packaging and/or re-working of packaged waste.

Transportation between facilities

Once a disposal facility is constructed and regulatory authorisation has been given to accept wastes for disposal, waste will need to be transported safely and securely to the facility from the sites where it is being stored. International standards and guidance for the safe transport of radioactive materials have been developed on the basis of world-wide experience and best practice. This experience is distilled into the International Atomic Energy Agency (IAEA) Transport Regulations, which apply to road, rail, sea and air transport of radioactive materials. Within the Joint Programme, we anticipate sharing of good practice and experience to continue, particularly as advanced programmes move

closer to transport and emplacement of waste in Europe's first geological disposal facilities.

Radionuclide inventory and source term

The nature and quantity of wastes for disposal, including their chemical and physical form, their packaging / conditioning and their radionuclide and chemical composition are known as the radioactive waste inventory for disposal. Improved understanding of (i) the inventory, (ii) the radionuclide source term and (iii) more generally, the evolution of the waste behaviour throughout the planned interim storage, operational and post-closure phases of a geological disposal facility lifecycle is important for designing the disposal system.

For wastes, such as Spent Fuel or vitrified High-level Waste, their wasteform is fixed, and therefore their physical and chemical form is used as a direct input to design of the disposal system, including disposal packaging. For other wastes (e.g. long-lived ILW), where more varied processing and treatment options are encountered, some enhancements in the robustness of the wasteform (and disposal package), and its contribution to overall safety performance of the disposal system may be considered, and therefore may vary depending on the disposal approach and concept adopted by each disposal programme owner to complement site conditions. For these wastes, knowledge of the radionuclide and chemical inventory (including metals and organic compounds) and the chemical state of its components are important. Data quality of waste inventories is variable, with uncertainty often dominated by waste heterogeneity.

In general, only a small subset of radionuclides will dominate the post-closure safety case of a disposal facility. However, since the composition of a wasteform contributes to the overall performance of the disposal multi-barrier system, improved mechanistic understanding for the release kinetics of the radionuclide and chemical species may enhance understanding of the source-term for key species in performance assessments.

The source term for a wasteform is not always an intrinsic wasteform property but may also depends as well on its disposal environment. Oxidizing or reducing disposal environments or the presence of hydrogen are of particular importance for the source term from spent nuclear fuel waste packages. In the case of vitrified waste, strong coupling exists between the wasteform performance and the presence of near field materials (e.g. clay interactions with iron corrosion products). The presence of water vapor in unsaturated settings of disposal vaults, or water flow rates in saturated environments are also an important factor influencing the source term. Fundamental understanding of these couplings is available, but the long-term operation of the governing mechanism needs to be assured. Some work on natural analogue systems may help clarify such long term post-closure process understanding.

The EC CAST project (2013- March 2018) provided understanding of the ^{14}C source term (focused on speciation) for graphite, activated metals (Zircaloy and stainless steel) and ionic exchange resins. Further understanding may be helpful, particularly in support of the disposal of intermediate and low-level wastes, in order to provide confidence that the environmental and radiological impact of any release of these species will be acceptable. The management of some radioactive waste is still a challenge, while for some others there is the potential for optimisation. This includes operational wastes, by-products from existing processes (e.g. sludges), chemically reactive wastes, irradiated graphite, etc. Radioactive waste treatment processes (for example, thermal treatment) could be applied to a wide range of waste streams and could provide benefits in feasibility to meet waste

acceptance criteria at a disposal facility, safety demonstration, volume and hazard reduction and cost savings.

Regarding spent fuel, the EC FIRST Nuclides project aimed to determine the fraction and the chemical form of some relevant elements, mainly ^{14}C, ^{36}Cl and ^{79}Se. Quantification of the activation products ^{14}C and ^{36}Cl that arise from N and Cl impurities in fuel, and understanding the impurity level ranges in fuels from different suppliers is still an open question identified at the end of the project. Internationally, considerable effort has been devoted to the long-term consideration of fission and activation product releases from spent fuel that may become exposed to groundwater once its container is breached (post-closure/disposal phase).

Waste acceptance criteria

As programmes move close to implementation, understanding of the nature and quantities of waste becomes formalized by waste acceptance criteria (WAC). This criteria includes a set of requirements for each waste management facility (including a geological disposal facility), taking into account specific characteristics of the waste to be disposed, the disposal concept adopted, and local site conditions. International cooperation and coordination in developing better understanding of the processes governing the source term and how this translates into waste acceptance criteria, as well as its use in the safety assessment, requires ongoing development.

Multi-national, regional or shared facilities

Some programmes across Europe consider the feasibility of regional or shared facilities (including multi-national repositories) that can provide infrastructure for all, or part, of the waste management route for a specific waste type. Planning of such facilities encompasses important and innovative developments (including the legal framework), which have been considered in work under the auspices of the EC or IAEA (See, IAEA - Developing multi-national radioactive waste repositories). Within the Joint Programme, scope undertaken to understand waste management routes, as part of pre-disposal activities may consider aspects that are important to those national programmes that consider the use of multi-national, regional or shared facilities.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[3]:

Scientific Theme 2: Radioactive waste characterisation, processing and storage (Pre-	• **Identifying good practice in the management of inventory data and uncertainty treatment.** - Expected outcomes and impact: Improved understanding of those species that dominate the transport, operations and post-closure safety cases and targeted fit-for-purpose assay that can enable cost-effective data quality improvements (J1.1.1/High). - Cooperation and relevant past projects: EC FIRST Nuclides project
	• **Developing novel conditioning technologies for non-mature and problematic waste.**

[3] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

disposal activities), and source term understanding for disposal.	- Expected outcomes and impact: Identification and sharing of good practice and in waste conditioning and packaging approaches for problematic wastes (J1.1.3/High). - Cooperation and relevant past projects: Check for EU-wide waste producers forum?
	• **Improved understanding of radionuclide release from existing and future wasteforms other than Spent Fuel.** - Expected outcomes and impact: Improved understanding of the radionuclide release mechanisms and associated kinetics for vitrified waste (ILW and HLW), metallic wastes, high organic content wastes, graphite, and cementitious wasteforms (J1.1.4/High). - Cooperation and relevant past projects: EC CAST project
	• **Developing reliable and affordable technologies for the radiological characterization and segregation of historical preconditioned radioactive waste.** - Expected outcomes and impact: Develop and demonstrate enhanced and/or novel non-destructive assay techniques (which maintain waste package integrity and containment) to provide quality assurance of packages being stored, transported or received at a disposal facility (J1.1.2/Medium). - Cooperation and relevant past projects: EC CHANCE project
	• **Improved understanding of the impacts of extended storage on waste package performance.** - 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 (J1.2.2/High). - Cooperation and relevant past projects: ?
	• **Improved understanding of the generation and release of radioactive trace gases and bulk gases from wasteforms and waste packages.** - Expected outcomes and impact: To further understand bulk gas generation from ILW, and gas generation from HLW and spent fuel, and potential impacts on the disposal system. To identify and resolve outstanding RD&D requirements arising from the EC CAST project, to increase understanding of the generation and release of gases (H2, CO2, CH4, HCl, CO, HF, HCN, etc.) resulting from radiolysis of polymers, including the influence of temperature, and to increase understanding of the generation and release of hydrogen resulting from corrosion (J1.4.2/High). - Cooperation and relevant past projects: EC CAST project
	• **Demonstration of geopolymer performance in representative disposal conditions.** - Expected outcomes and impact: To develop an appropriate understanding of the radiolytic performance and product stability, gas-permeability, resilience to cracking from gas production, fire performance and long-term chemical stability (leach performance) of geopolymers used for waste solidification in the context of the disposal environment (J1.1.5/Medium). - Cooperation and relevant past projects: Existing development group?

	• **Improved understanding of the nature and quantities of the likely chemotoxic component of common wastes.** - Expected outcomes and impact: Enhanced confidence in packaging and conditioning methods, and of the long-term environmental and radiological impact of wastes containing chemotoxic elements (J1.1.7/Medium). - Cooperation and relevant past projects: Existing development group?
	• **Optimisation of radioactive waste treatment techniques where there is potential for volume/hazard reduction and potential cost savings.** - Expected outcomes and impact: Optimisation of waste treatment options leading to potential benefits in terms of Waste Acceptance Criteria, safety demonstration, volume and hazard reduction and cost savings (J1.1.8/Medium). - Cooperation and relevant past projects: EC projects CAST, Carbowaste and THERAMIN
	• **Improved understanding of the behaviour of packaged Spent Fuel for a range of hypothetical fire and impact scenarios during operations and transport, and consolidation of existing understanding of post-closure Spent Fuel release processes.** - Expected outcomes and impact: Improved mechanistic understanding of the release of fission products from the different types of spent fuels to better predict the radionuclide source term for operational and post-closure safety assessment (J1.1.9/Medium). - Cooperation and relevant past projects: EC projects SFS, MICADO, FIRST Nuclides, DISCO
	• **Fourth generation (Gen (IV)) wastes.** - Expected outcomes and impact: To understand the nature and quantities of wastes arising from a fourth generation of nuclear reactors, identify challenges to the disposal of such wastes and enable early feedback to reactor system designers in order to mitigate associated risks (J1.1.6/Low). - Cooperation and relevant past projects: ?
	• **Quantification of fissile content of spent fuel.** - Expected outcomes and impact: Improved understanding of the characteristics of spent fuel (J1.1.10/Low). - Cooperation and relevant past projects: ?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 2: Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal:

Strengthened links between Implementers and Waste Producers: To enhance cooperation in the process of spent fuel and nuclear waste disposal solutions and to improve understanding of spent fuel arisings, including those from innovative fuel types (J3.7)

Inventory collation and forecasting: To ensure that all countries implementing a disposal facility develop a comprehensive inventory (J3.5).

Methodologies applied to define radionuclide inventories: To further understand evolution of the radionuclide inventory after disposal including the use of radionuclide vectors, and uncertainties about databases of radionuclide properties (J3.6).
Understanding of the potential for long-term storage as a management option for disused sealed radioactive sources: To understand the potential impact of improving technology for the treatment or re-use of disused sealed radioactive sources as an alternative to disposal (J3.10).
Management of damaged waste packages and the criteria and methods for reprocessing aged waste: To share good practices with respect to minimising radiological consequences and addressing 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 (J1.2.4)
Operational lifespan of interim storage facilities: To support the safe management and safety assessment of existing storage facilities and design criteria for new storage facilities (J.2.4.5).
Waste acceptance criteria: To develop good practice guides for the derivation of waste acceptance criteria and increase confidence in, and further refinement of, inventory uncertainty quantification methods, including sensitivity studies (J2.1.6).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 2:

With the purpose of sharing experience and knowledge on waste management routes between interested organisations from different countries, with programmes at different stages of development, with different amounts and types of radioactive waste), a strategic study (EURAD WP9-ROUTES) has been initiated to look holistically at waste management routes in Europe from cradle to grave. Specifically this will look across the spectrum of challenging wastes, characterisation approaches and waste acceptance criteria established across Europe, and identify areas of focus for the EURAD in the future.

The EC Horizon2020 call, supported 4 projects running from 2017-2021 which will contribute further understanding and knowledge to address remaining challenges in Scientific Theme 1 - CHANCE, DISCO, INSIDER and Theramin.

The CHANCE project aims to address the as yet unsolved and specific issue of the characterization of conditioned ILW radioactive waste (CRW). CHANCE will establish a comprehensive understanding of current characterization methods and quality control schemes for conditioned radioactive waste in Europe. CHANCE will develop, test and validate already-identified and novel new techniques that will undoubtedly improve the characterization of CRW. One of the project's key tasks will be identification of links and overlaps between waste acceptance criteria and actual waste characterization technologies available, in order to identify specific, as yet unsolved, methodology issues and technology gaps.

The DISCO project aims to fill the gap of knowledge on spent fuel dissolution arising from the development and use of novel types of fuel (Cr-doped and MOX). The project aims to enhance understanding of spent fuel matrix dissolution under conditions representative of failed containers in reducing repository environments and to assess whether novel types of fuel behave like the conventional ones. This project aims to expand the database on spent fuel dissolution with results from dissolution studies. The effects of dopants will be investigated through experiments using both spent nuclear fuel and synthetic materials specifically designed for

the project. In addition, chemical modelling will be employed to enhance understanding.

The INSIDER project aims to develop new methodologies for more accurate initial estimation of contaminated materials, resulting waste volumes and timely planning during decommissioning and dismantling (D&D) operations. The envisaged project outcomes will enable building of a fit-for-purpose representation of the radiological status of facilities (or components), at a relevant precision level allowing improved decision making when considering different D&D scenarios and options.

The Theramin project is focussed on thermal treatment for radioactive waste minimisation and hazard reduction. Relevant technologies include in-container vitrification, gasification, plasma treatment and hot isostatic pressing. Project outputs will provide an EU-wide strategic review and assessment tool to assess the value of thermal technologies applicable to a broad range of waste streams (ion exchange media, soft operational wastes, sludge, organics and liquids). This will include the applicability and achievable volume reduction of the technologies through 'first-of-a-kind' active and non-active full-scale demonstration tests, and will assess the disposability of residues. THERAMIN will establish a pan-European network of expertise on thermal treatment, will provide for cross-European technology transfer, and will identify prospects for sharing of facilities between countries facing similar problems.

Within the Joint Programme first phase, an RD&D work package on spent fuel characterisation and evolution has been established. This will study the properties, behaviour and associated uncertainties of spent nuclear fuel from the time when it is irradiated in the reactor up to the time it is emplaced in a geological disposal facility. Both experimental and numerical activities are proposed. The work seeks to understand fundamental out-of-core behaviour of fuel and cladding to ultimately ensure safe, reliable and economical use of storage and disposal systems. The work package includes Knowledge Management activities, including a state-of-the-art review on spent fuel characterisation and sources of uncertainties, and the development of guidance for model calculations, radionuclide inventory calculations, characterization methods and uncertainties calculations for spent fuel.

Theme 3: Engineered barrier system (EBS) properties, function and long-term performance

Introduction and background:

Spent Fuel and high-level waste disposal canisters

The conditioned waste is placed in a container (sometimes called a canister), creating what is referred to as the waste package. The container must be chosen so that the waste can, if needed, be safely transported and handled leading up to its disposal. The material and design of the container can be chosen to then provide reliable physical containment under disposal conditions for extended periods of time. This can be achieved in a variety of ways, for example, in the case of metallic containers, by using a metal such as copper that is highly corrosion-resistant under certain chemical conditions or by using sufficient thickness of a metal such as carbon steel so that it will take a long time to be corroded through. For HLW and Spent Fuel, packaging developments are relatively mature and hence a continued exchange on latest developments is envisaged within the Joint Programme. With new waste streams (advanced fuel cycles) and new host rock systems under consideration, alternative container materials for HLW/SF may be considered.

Containers for long-lived intermediate and low level wastes

For intermediate and low-level wastes, stainless steel, ductile cast iron and concrete containers are typically considered. Such containers have been used to package wastes across Europe, and therefore there is a wealth of existing information that can be shared through cooperation actions.

Clay-based backfills, plugs and seals

The backfill (or buffer) in this context refers to material that is placed immediately around emplaced waste containers in a disposal facility. The material and design can be chosen so that the buffer or backfill provides one or more beneficial functions.

Many studies have been performed to characterise the behaviour of swelling clay, including bentonites. The main requirements are on swelling capacity to fill the technological voids and on low hydraulic conductivity. This implies a good understanding of physical processes that occur throughout the lifecycle of the bentonite component (EBS, sealing or backfill) and a capacity to perform robust predictive simulations. Studies have concerned several types of bentonites in several physical forms, such as compacted blocks or pellet mixtures. Investigations of the behaviour of bentonites under particular conditions associated with their use in an industrial context need to be pursued. Especially, the role of heterogeneities due to installation or to external conditions such as local water inflow or temperatures in excess of 100°C. Such phenomena may lead to changes in the mineralogical composition of the bentonite, particularly in its clay content. These changes may affect the component as a whole (e.g. illitization) or an interface zone with the perturbation source (e.g. alkaline transformation).

For clay-based materials (e.g. bentonite) intended for use as a seal or to backfill galleries in the disposal facility, ongoing needs are also recognised. The main need is to consolidate the long-term performance of the seals at the component scale, taking into account all the (T)HMC perturbations between the different materials (concrete, bentonite, host-rock). For instance, there is still a need to improve our understanding of the consequences of chemical interactions at the interface between clay-based materials and

concrete on long-term THM behaviour of the seals.

Cementitious-based backfills, plugs and seals

Cement-based backfills are envisaged for a number of disposal facilities for intermediate level wastes across Europe, and are commonly used as liners in disposal cells or as part of waste containers in many Member States existing facilities for low level waste / near-surface disposal. Further understanding is required to support their use as a backfill material for longer-lived wastes in geological disposal, particularly to understand their contribution to overall system performance during late post-closure timeframes. For cementitious materials, their physical behaviour, especially during the operational phase and post-closure THM-transient periods, is strongly influenced by boundary conditions, controlled by both the disposal system and the host rock (water saturation, temperature, etc.). To assess the evolution of the performance of the cementitious components these studies have to be extended to a longer time-period, considering various operating conditions.

Cementitious materials are also extensively planned to be used as disposal structures (buffer, plugs, waste matrices) which require further understanding of their long-term degradation behaviour, including the impacts of organics. This is especially the case for low pH cements.

Salt backfills

Salt backfill regimes and seals are essential elements of the EBS for a HLW repository in salt.

EBS system understanding

At the disposal-cell scale, once packaged wastes, and backfills and seals are emplaced in the disposal facility, the spectrum of processes and interactions to be considered in the performance assessment is rather broad and covers waste-container, container – backfill/buffers, and waste package-host rock interactions. Regarding data and models to support the long-term safety assessment, feasible and well-instrumented integral experiments and improved models may provide for more realistic understanding of engineered barrier system (or near-field) evolution and related uncertainty treatment.

Across the range of backfill and buffer materials under consideration, there is a need for improved understanding of the coupled mechanical/chemical evolutions at the interfaces with the waste package materials (glass/iron/clay, cement/bentonite, cement/metal, bentonite/metal) and between these materials and the host rock (iron/clay interactions, alkaline perturbation). Of particular interest are unsaturated conditions, where glass is corroded by water vapor. Understanding further relatively ‘short-term’ interactions (e.g. resaturation) versus ‘long-term’ interactions (e.g. development of gas pressure, backfill degradation etc.) occurring at interfaces is considered important. Another perturbation which has to be addressed is the influence of gases and microbes on geochemistry. These studies need to be supported by mock-ups (at different scales) and in-situ experiments to verify that the components will behave as expected and that all the relevant processes have been taken into account, but also to demonstrate the ability to build complex components (buffer, plugs and seals).

Co-disposal of radioactive waste of different classifications or properties may be possible in some geological disposal facilities. Interactions between wastes with different properties may occur, unless only one type of waste is disposed of (e.g. spent fuel, vitrified waste, etc.). Even when disposing of one waste type, such as long-lived alpha containing waste, the diversity of the waste may lead to a situation where dissolution plumes can influence each

other. Therefore there is an ongoing interest in optimisation of the disposal of wastes with differing characteristics and properties and the appropriate selection of engineered barrier materials when co-disposed in a single geological facility.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[4]:

Scientific Theme 3: Engineered barrier system (EBS) properties, function and long-term performance	• **Improved understanding of the interactions occurring at interfaces between different barriers including waste packages in the disposal facility.** - Expected outcomes and impact: Knowledge of the physical and chemical transformations at the interface between waste packages and different barriers and materials and development of pore-scale models describing the impact on 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 (J1.2.1/High). - Cooperation and relevant past projects: ?
	• **Characterised bentonite / clay-based material evolution under specific conditions to provide data on hydro-mechanical, thermal and chemical behaviour.** - Expected outcomes and impact: Enhanced understanding of post-closure safety considerations of bentonite and clay-based materials by extensive characterisation of different phenomena, including variations of properties arising from barrier installation, hydration history, elevated temperatures and chemical influences on long-term evolution behaviour (J1.3.1/High). - Cooperation and relevant past projects: EC BENIPA and BELBaR project
	• **Improved chemical and microbial data to better quantify gas generation and the consequences of microbial processes.** - Expected outcomes and impact: Improved mechanistic understanding, rather than bounding assumptions, to quantify kinetics of microbial catalysis of both gas consumption or gas production reactions, and the competition between them, and improved understanding of the topological description of rock surfaces interacting with gases (J1.3.2/High). - Cooperation and relevant past projects: EC MIND project
	• **Improved quantification and understanding of cement-based material evolution to improve long-term modelling and assessments.** - 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 (temperature, radiation, redox etc.) and considering hydromechanical behaviour (shrinkage and creep), and passive and active corrosion impacts (J1.3.3/High). - Cooperation and relevant past projects: EC CEBAMA project
	• **Improved understanding of the impacts of different metallic and cementitious component phenomena on near-field evolution via improved models.**

[4] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

	- 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) (J1.3.5/High). - Cooperation and relevant past projects: EC projects CAST, Carbowaste and THERAMIN
	• **Improved understanding of gas reactivity in the EBS.** - Expected outcomes and impact: Increased understanding of gas reactivity in the EBS and host rocks under representative conditions and its potential impacts on geochemistry, safety-relevant processes and radionuclide migration (J1.4.4/High). - Cooperation and relevant past projects: ?
	• **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 (J2.2.2/High). - Cooperation and relevant past projects: EC projects RESEAL II, DOPAS
	• **Developing alternative HLW and Spent Fuel container material options and improved demonstration of their long-term performance.** - 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 (J1.2.3/Medium). - Cooperation and relevant past projects:
	• **Improved understanding of low pH cements.** - Expected outcomes and impact: Increased understanding of low pH cements and their evolution (pH, mineralogy), including their composition, their potential for retarding particular radionuclide migration, determining suitable methodologies for measuring the pH of cements, understanding of the reinforcement corrosion process in low pH concrete if reinforced concrete is used, and their behaviour under high temperatures (up to 90 °C) (J1.3.4/Medium). - Cooperation and relevant past projects: EC CEBAMA project
	• **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 understanding of coupled interactions between reactive transport models, the waste alteration (e.g. corrosion of glass, polymer radiolysis/hydrolysis, etc.) and near-field materials (e.g. steel, concrete, etc.) (J1.3.7/Medium). - Cooperation and relevant past projects: ?
	• **Improved understanding of a salt backfill.** - Expected outcomes and impact: Improved understanding of the long-term behaviour and properties of a salt backfill, including influences of pressure and temperature on behaviour (J1.3.6/Low). - Cooperation and relevant past projects: EC BAMBUS II project, NEA-Salt Club

	• **Identify co-disposal interactions of importance to long-term safety.** - Expected outcomes and impact: Identified waste types and compositions that can generate plumes problematic for the integrity and retention of other wastes in a single facility and assessment of their potential impact on safety to support design optimisation (1.3.8/Low). - Cooperation and relevant past projects: ?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 3: Engineered barrier system (EBS) properties, function and long-term performance

Use of clay-based materials in a geological disposal facility: To understand the properties and performance of different clay-based materials depending on their origin or mineralogy (1.3.1).
Low pH cement understanding: To consolidate existing knowledge on low pH cements, including their composition, impact on radionuclide migration and practical implementation (1.3.4).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 3:

There are several ongoing EC projects that will provide information and knowledge to support understanding of the Engineered Barrier Systems. The Horizon 2020 call supported the EC BEACON project running from 2017-2021 which will develop and test the tools necessary for assessment of the hydro-mechanical evolution of an installed bentonite barrier and its resulting performance in a disposal facility. Now that several European national programs are moving towards licensing, construction and operation of repositories, verification of EBS component behaviour is of high common interest. Therefore within BEACON, cooperation between design and engineering, science and performance assessment experts is planned in order to verify the performance of current designs for buffers, backfills, seals and plugs as part of the EBS.

A project nearing completion with outputs of direct relevance to this Theme includes the EC MIND project. It is a unique multidisciplinary project which brings together a broad range of leading research institutions and stakeholders in the field of radioactive waste disposal. The project aims to reduce uncertainty of safety-relevant microbial processes controlling radionuclide, chemical and gas release from long-lived intermediate level wastes (ILW), high-level waste and spent fuel geological disposal. Outputs will be of direct relevance to several of the JP first phase projects described herein, so supporting ongoing dissemination activities with the knowledge management activities is recognised.

Completing in 2019, the CEBAMA project addresses key issues of relevance for long-term safety and key scientific questions related to the use of cement-based materials in nuclear waste disposal applications. It includes materials used as waste forms, liners and structural components as well as sealing materials in a broad variety of applications. It aims to provide insight on general processes and phenomena and to develop a model for predicting the transport characteristics such as porosity, permeability and diffusion parameters of cement-based materials in contact with the engineered and natural barriers of repositories in crystalline and argillaceous host rocks.

Within the Joint Programme first phase, a work package is included to understand the influence of temperature on clay-based

material behaviour. Both clay host rock and bentonite buffer and their behaviour at high temperature are included (ranging from 100 °C to ~150°C). Mechanical behaviour is the focus area, with an overall objective to evaluate whether an increase of temperature is feasible and safe. The programme of work will aim to provide results that are applicable to a wide range of buffer material and clay host rocks, which can be useful for different national programmes.

Within the Joint Programme a work package is included to support the assessment of the chemical evolution at the disposal cell scale . It considers interactions between disposal system components/materials and thermal, hydraulic and/or chemical gradients of relevance to ILW and HLW disposal concepts. The study of the disposal cell in this work package ranges from microscale processes at interfaces between different materials up to interactions of waste packages with their immediate surrounding near field environment and the host rock. The main objective is to identify, understand and describe the relevant processes driving the chemical evolution within selected generic disposal cell designs by analysing and combining information from available experimental studies and modelling exercises at both the process and system levels.

Also supported within the Joint Programme is a work package dedicated to cement-organics-radionuclide-Interactions (CORI). Organic materials are present in some nuclear wastes and as admixtures in cement-based materials and can potentially influence the performance of a geological disposal system, especially in the context of low and intermediate level waste disposal. Therefore CORI aims to develop improved knowledge on organics degradation, organics-cement-interactions, and radionuclide-organics-cement-Interactions, all within the content of the post-closure radionuclide transport pathway for geological disposal facilities for ILW and LLW/VLLW, including surface/shallow disposal.

Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution

Introduction and background:

Long-term stability (uplift, erosion and tectonics)

A site should be geologically stable in order to ensure safety and also be predictable over long timescales to the extent required for assessing safety performance. A stable geological environment is not likely to be subject to sudden or rapid detrimental changes over long timescales because of its resilience with respect to internal and external perturbations. The geosphere contributes to isolation by providing a stable location deep underground that protects the geological disposal facility from any significant perturbations to the natural environment that may occur over the timescales of interest. The geosphere also contributes to containment by delaying the movement of any potential small amounts of long-lived radionuclides that are released from the EBS/near field, enabling their decay before they can pose a hazard to the biosphere.

The natural processes which may impact on the geosphere over the very long timescales associated with geological disposal are tectonics, uplift or subsidence and erosion,

and the impacts of future climate, particularly potential future glaciations and related subglacial erosion and permafrost formation. Processes generally occur more slowly at depth; therefore reasonable predictions of long-term behaviour and evolution can be made.

Perturbations (gas, temperature and chemistry)

The properties of the host rock and geosphere control the slow release and migration of radionuclides in both the gas and aqueous phase once released from the EBS. The key issues to be addressed depend upon the geological environment and the associated disposal concept for the facility.

In a low permeability host rock, such as the Clay stones or evaporites, there is the possibility that gas could be generated at a faster rate than it can be removed without inducing fracturing in the host rock. Thus, depending on the likely rates of bulk gas generation, the potential for significant over-pressurisation may need to be considered for these concepts. For a disposal facility in a fractured higher strength rock it is likely that transport of gas through the host rock would be sufficient to prevent significant over-pressurisation of the EBS. In several disposal concepts, the potential for migration of free gas containing gaseous radionuclides to the biosphere is an important issue.

The EC FORGE (Fate Of Repository Gases) project investigated gas migration issues of relevance to geological disposal performance assessment.

Further needs identified include water (including solutes) and gas transfer during the resaturation phase, and understanding further complexity with respect to the coupling between hydraulic and other processes. The coupling with thermal processes is already implemented in most of the two-phase flow numerical codes and can be used on large scales. Concerning mechanical coupling however, the high complexity of incorporating full coupling, limits for the moment its use to a restricted volume. Having a simplified version of such a coupling, enabling its use in a full scale two-phase flow evaluation, would be highly useful.

Aqueous pathways and radionuclide migration[5]

Regarding the aqueous phase releases, the rate of radionuclide migration depends not only on the distance of the disposal area from the biosphere and the rate of groundwater flow, but radionuclide migration is further retarded by the interaction of dissolved radionuclides with the diverse surfaces of wasteform and container degradation products, backfill materials, minerals and organic matter. Retention on solid surfaces may be reduced by the formation of soluble solution complexes and organic or inorganic colloids. The migration process is different for each type of radionuclide and influenced strongly by the geochemical environment.

There has been research on the various topics of radionuclide migration for more than 30 years, often funded by the European Commission. This has included both detailed mechanistic and applied studies. The present

[5] This includes scope related to radionuclide transport (in the aqueous and gas phase) through the EBS and host rock, in addition to the Geosphere.

programme focuses on remaining uncertainties related to the influence of temperature, organic ligands, microbial perturbations, colloidal interactions and redox conditions on radionuclide behaviour (within the engineered barrier system – in Theme 3) the excavated disturbed zone, host rock and the far field (i.e. the geosphere). Scope continues to include laboratory-scale experiments, modelling and also the upscaling of process understanding through the use of URLs and large-scale mock-ups and/or full scale in situ testing.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[6]:

Scientific Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution	• **To increase understanding of gas migration in different host rocks.** - Expected outcomes and impact: Further understanding of gas generation 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 (J1.4.1/High). - Cooperation and relevant past projects: EC CAST and GASNET Project
	• **Improved understanding of gas reactivity in different host rocks.** - Expected outcomes and impact: Increased understanding of gas reactivity in the EBS and host rocks under representative conditions and its potential impacts on geochemistry, safety-relevant processes and radionuclide migration (J1.4.4/High). - Cooperation and relevant past projects: ?
	• **Improved representation of sorption mechanisms and coupled chemistry / transport processes for various media.** - Expected outcomes and impact: To represent heterogeneous media (cement-based materials, clay-rock, crystalline rocks, bentonite, corrosion products…) in speciation, sorption (considering competitive effects) and transport models considering the variability of barrier properties at all scales (J1.5.2/High). - Cooperation and relevant past projects: EC CatClay project
	• **Improved understanding of bounding conditions for the effects of microbial perturbations on radionuclide migration to support performance assessments.** - Expected outcomes and impact: Quantification of microbe populations, energy and carbon source availability, and their impact on radionuclide migration, barrier performance and chemical environmental conditions as a function of time (J1.5.5/High).

[6] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

	- Cooperation and relevant past projects: EC project MIND
	• **Develop and implement two-phase flow numerical codes to increase gas transient representation at the disposal scale.** - Expected outcomes and impact: Increase the degree of representativeness of two-phase flow models which may be used at the disposal scale by increasing the level of coupling with mechanics especially (J1.4.3/Medium). - Cooperation and relevant past projects: ?
	• **Quantification of long-term entrapment of key radionuclides in solid phases to inform reactive transport models.** - Expected outcomes and impact: Experimental thermodynamic and kinetic data and supporting models to quantify mechanisms for irreversible entrapment in solid phases for key radionuclides (e.g. 14C and U as carbonates and 79Se in sulphur-bearing phases) (J1.5.3/Medium). - Cooperation and relevant past projects: Project SKIN (Slow processes in close-to-equilibrium conditions for radionuclides in water/solid systems of relevance to nuclear waste management).
	• **Improved understanding of the transport of strongly sorbing radionuclides.** - Expected outcomes and impact: Improved representation of heterogeneous media, anoxic environmental conditions, and retention of redox sensitive radionuclides or toxic elements in transport models (J1.5.4/Medium). - Cooperation and relevant past projects: EC projects SKIN, CatClay
	• **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 (J1.5.6 & J1.5.10 / Medium). - Cooperation and relevant past projects: ?
	• **Improved understanding of the influence of temperature on radionuclide migration and representation of effects in geochemical models.** - Expected outcomes and impact: Improved understanding of sorption constants for radionuclides (distribution coefficients or surface complexation constants) as a function of temperature, groundwater composition as a function of temperature, and the effect of temperature on potential transformations of solid phases, radionuclide speciation and any associated impact on solubility (J1.5.7/Medium). - Cooperation and relevant past projects: EC projects MIND
	• **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 (J1.5.8/Medium). - Cooperation and relevant past projects: EC project BELBAR
	• **Improved understanding of the influence of redox on radionuclide migration.**

	- Expected outcomes and impact: Improved understanding of the temporal and spatial evolution of redox conditions in engineered barrier systems, the effect of redox perturbations able to modify the expected oxidation states (and mobility) of radionuclides, and the role of kinetics of radionuclide reduction/oxidation (J1.5.9/Medium). - Cooperation and relevant past projects: EC project ReCosy
	• **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 (J1.5.11/Medium). - Cooperation and relevant past projects: EC project Carbowaste, CAST
	• **Enhanced treatment of climate change, non-human biota, land-use and parameter derivation in biosphere models** - Expected outcomes and impact: To enhance understanding of biosphere processes so as to improve safety case confidence (J2.2.6/Medium). Cooperation and relevant past projects: EC projects BIOCLIM, BIOMOSA
	• **Developing models of groundwater evolution.** - 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 (J1.6.3/Medium). • Cooperation and relevant past projects: ?
	• **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 (J1.6.1/Low). - Cooperation and relevant past projects: EC CROCK project
	• **Improved understanding of the impact of rock-matrix diffusion on radionuclide travel time through the geosphere.** - Expected outcomes and impact: Improved understanding of the impact of rock-matrix diffusion on radionuclide travel time through the geosphere (J1.6.4/Low). • Cooperation and relevant past projects: ?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution

Impact of rock matrix diffusion on travel time through the geosphere: To ensure that learning from site characterisation activities in advanced programmes is disseminated to less-advanced programmes (J1.6.4).

Development of site evolution models, and how to manage data as it is obtained during the site characterisation phase: To further knowledge on site evolution models, and how the physical,

geochemical, geotechnical and hydrogeological properties of the host rock and disposal facility change over time (J3.2).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 4:

Within the Joint Programme a work package on mechanistic understanding of gas transport in clay materials is included. It aims to determine the range of conditions under which each identified gas transport regime is possible, in clay materials representative of the potential host rocks (and EBS components – relevant for Theme 3) considered in Europe. In this way, data will be obtained in conditions spanning low (diffusion) to high (advection) gas generation rates. For each of these gas transport regimes, the effects on performance related properties of the materials being tested will be investigated. The experimental effort will be complemented by the development and evaluation of modelling tools for simulating gas transport in clay-rich media for a wide range of gas transport regimes.

Also supported by the Joint Programme is a work package which is focussed on fundamental understanding of radionuclide retention. Scope covers radionuclide and chemical species migration focussed on sorption processes, heterogeneous redox processes and in particular overall radionuclide mobility in "real" systems. Regarding sorption, the work package will address open issues on sorption reversibility, uptake mechanisms (adsorption vs. incorporation), molecular structure of surface complexes, effect of temperature as well as the thermodynamics of porewater-surface interfaces (acid/base surface properties, Kw), sorption site density (e.g. accessibility), sorption competition and surface diffusion. Investigations on surface induced (heterogeneous) redox processes will provide a better understanding of the coupled sorption and electron transfer interface reactions governing the retention of redox-sensitive radionuclides at Fe(II)/Fe(III) bearing minerals surfaces so as to improve our capacity to model, and thus predict, the fate of these elements in the context of radioactive waste storage. Studies on the mobility of radionuclides in "real" clay rocks as well as crystalline rocks will provide insight into the role of microstructures and the impact of chemical boundary conditions on radionuclide migration.

Theme 5: Geological disposal facility design and the practicalities of implementation

Introduction and background:

Facility and disposal system design

The feasibility and suitability of a selected or preferred disposal concept(s) is an ongoing activity to review design and layout of the disposal system, together with the associated evaluation of operational and long-term safety and an assessment of socio-economic aspects. With respect to overall concept feasibility assessment, a common view on areas of significant safety impact could be identified and proposal formulated for appropriate degree of regulatory control. As disposal programmes progress through successive stages of development, the process for concept adaptation and optimisation requires careful consideration.

An important part of the facility design is asset management, which refers to the strategic plan, processes and actions that are needed to upkeep the disposal facility production system in an efficient and effective manner over the

whole life cycle of the system. Engineering asset management offers a set of processes, methods and tools for system reliability evaluation, life cycle cost assessment, maintenance development and setting Key Performance Indicators for asset management operations.

Constructability, demonstration and verification testing

There is a need to demonstrate that the concepts for disposal are practical in terms of their actual implementation in a host rock. There are many aspects to this, from large-scale testing of systems and equipment, to iterating the final design of the facility to allow for adaptations to actual site conditions. This is often referred to as the industrialisation phase of a disposal programme which, together with optimisation activities (including optimisation of radiation protection), remains a key part of advanced programmes currently moving towards construction and operations.

Once facilities become operational, there will be an ongoing need to evaluate the behaviour of key components of the disposal system, or the impacts of the disposal system and its operation on the environment – and thus to support decision making during the disposal process and to enhance confidence in the disposal process. Observations may be continuous or periodic in nature, and may include measurements of engineering, environmental, radiological or other parameters and indicators / characteristics.

Health and safety during transport, construction, operations and closure

During facility operations, all activities performed shall respect the requirements of long term safety. Nevertheless, some technologies and practices, if improperly implemented, may result in harm to workers and negative impacts on the long-term performance of the disposal system. It would therefore be beneficial to share lessons learned from other operational experience, incidents and health and safety -related accidents internationally.

Monitoring and retrievability

During the operational phase of a geological disposal facility it is likely that appropriately selected parameters will be monitored in order to provide reassurance of the as-built integrity of the disposal facility. In practice, the selection of monitoring technologies is based on the safety case, concept and requirement for each parameter (measuring period, frequency). Although considerable effort has been invested, further development utilising evolving technologies would be beneficial. The combination of non-invasive techniques is considered an essential aspect of monitoring due to their advantages over common intrusive methods. The ambition includes an increase in the range of physical and chemical properties that are monitored to allow the means for cross-correlating monitoring results.

Monitoring technology selection is also based on the need to provide minimal disturbance to the engineered barriers. R&D is necessary in order to develop and characterise improved monitoring technologies that will not disturb the disposal cell, seal and plug, and that may be functional for long periods of time (for example, in excess of one hundred years).

Retrievability of wastes and reversibility of waste emplacement and decision making during implementation are treated at the national level, as they are pursuant to local and national requirements and legislation. How such requirements impact on design criteria has been an area of ongoing work within EC projects and NEA initiatives. Some technologies for retrievability of wastes packages were developed and tested within the EC ESDRED project, however further work is identified to continue development of technologies to retrieve waste packages (e.g. development of robots and sensors). Likewise, many challenges remain with respect to

reversibility of decisions, including those related to safety and the economy.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[7]:

Scientific Theme 5: Geological disposal facility design and the practicalities of construction, operations and closure	• **Developing monitoring strategies appropriate to the operational phase (including facility construction and work acceptance) of geological disposal facilities that will not adversely affect the performance of the disposal system** - 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 (J2.5.1/High). - Cooperation and relevant past projects: EC Projects SOMOS, MoDeRn, MoDeRn 2020.
	• **Developing innovative monitoring technologies.** - Expected outcomes and impact: To develop innovative technical solutions and improvement of existing technologies to facilitate the integration of monitoring technologies into the final repository design and to maintain the reliability of the monitoring systems (J2.5.3/High). - Cooperation and relevant past projects: EC Project MoDeRn 2020.
	• **Developing appropriate monitoring technologies for closure and a period of post-closure institutional control in links with relevant parameters for safety.** - Expected outcomes and impact: 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 including the development of appropriate monitoring techniques (e.g. wireless transmission, large energy autonomy technologies) (J2.5.2/Medium). - Cooperation and relevant past projects: ?
	• **Optimisation of backfilling and other major implementation processes, including waste emplacement, retrieval and sealing technologies.** - Expected outcomes and impact: To characterize 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 (J2.5.7/Medium). - Cooperation and relevant past projects: ?
	• **Developing cost-effective asset management strategies for use in the design.** - Expected outcomes and impact: To enable definition of the requirements arising from the upkeep and improvement of assets in the facility design, including a preliminary asset management strategy (J2.5.8/Medium)

[7] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

	- Cooperation and relevant past projects: ?
	• **Developing operational hazard assessment methodologies (inc. flooding risk)** - Expected outcomes and impact: To identify potential pathways for water ingress from representative geological disposal facility designs. To assess impacts of flooding on operational safety and long-term safety and performance (J2.4.2/Low). - Cooperation and relevant past projects: ?.
	• **Improved understanding of waste package durability and disposal facility infrastructure with respect to retrievability.** - 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 (J2.5.4/Low). - Cooperation and relevant past projects: EC ESDRED project
	• **Assessment of the technical feasibility and lifecycle adaptation of a geological disposal concept for a specific site and specific nuclear waste type.** - Expected outcomes and impact: Development of a common view on areas of significant safety impact with respect to technical feasibility of a geological disposal concept. Development of change control approaches to appropriately capture design adaptation and feedback into safety assessment (J2.5.5& 3.8/Low). - Cooperation and relevant past projects:?
	• **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 (J2.5.6/Low). - Cooperation and relevant past projects:?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 5: Geological disposal facility design and the practicalities of construction, operations and closure

Accident management and emergency preparedness: To improve the understanding of potential safety issues with regards to RWM, including disposal (J2.4.4).
Asset management: To develop criteria for managing assets that balances risk, cost and benefit of the assets over their life cycles and evaluate alternative scenarios for asset management approaches (J2.5.8).
Managing co-disposal: To optimize the use of geological facilities by enabling disposal of wastes with a variety of compositions and properties (J3.12).
Radiation protection optimisation principle: Improved methodologies for applying the principles of 'Best Available Technology' (BAT), 'As Low As Reasonably Practicable' (ALARP) and 'As Low As Reasonably Achievable' (ALARA) to disposal system development to ensure the safety and radiological risks resulting from the disposal system throughout its lifecycle are reduced so far as

reasonably practicable and immediate (operational) risks are balanced against the post-closure risk (J3.13).
Reversibility: To develop a common position across Europe, and to exchange good practices (J3.17).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 5:

Based on the outcomes of the EC MODERN project, collaborative efforts continue through MODERN2020 on monitoring technologies and strategies for use in a geological disposal. It aims to provide the means for developing and implementing an effective and efficient repository operational monitoring programme, that will be driven by safety case needs, and that will take into account the requirements of specific national contexts (including inventory, host rocks, repository concepts and regulations, all of which differ between Member States) and public stakeholder expectations (particularly those of local public stakeholders at (potential) disposal sites). The work in the Modern2020 Project will address: i) Strategy: development of detailed methodologies for screening safety cases to identify needs-driven repository monitoring strategies and to develop operational approaches for responding to monitoring information; ii) Technology: carry out research and development (R&D) to solve outstanding technical issues in repository monitoring, which are related with wireless data transmission technologies, alternative long term power supplies, new sensors, geophysics, reliability and qualification of components.; iii) Demonstration and Practical Implementation: enhance the knowledge on the operational implementation and demonstrate the performance of state-of-the-art and innovative techniques by running full-scale and in-situ experiments; and iv) Societal concerns and Stakeholder Involvement: Develop and evaluate ways for integrating public stakeholders concerns and societal expectations into repository monitoring programmes.

Theme 6: Siting and licensing

Introduction and background:

The selection of a site (or sites) for a geological disposal facility is clearly the most important challenge to the successful implementation of long-term management of radioactive wastes. Therefore this topic is of great interest to early-stage programmes that have yet to identify a preferred site for a geological disposal facility, including in this case those programmes that have experienced reversals in past site selection projects. This theme represents the clearest example of the importance of societal engagement in decision-making, including the necessity to engage at national, regional and local community levels. This engagement has to take full account of the relevant formal policies, legislation and regulations laid down by society. An implementing organisation must earn “a licence” to proceed at all stages of its programme and this typically translates into a formal regulatory requirement for licensing at key stages. Site selection policies and procedures, regulatory arrangements and licensing requirements vary between member states, reflecting inter alia the socio-political context, geological factors, and the waste inventory. Therefore there is no single best practice in meeting this key challenge, but there are common components that can contribute to a successful outcome. These form the basis for JP activities on this theme.

Site selection process

The process to be followed in selecting a site for a GDF is typically determined at national government level but, in establishing the relevant policy, the implementing organisation, regulators and civil society are likely to be required to play a part. Increasingly emphasis is placed upon the involvement and support of potential, “host” communities that would be most affected by

eventual development of a GDF. The process is likely to involve the initial evaluation of a number of potential sites with a progressive narrowing down, eventually to identify a single preferred site. In order to maximise the prospect of a successful outcome, the stakeholders and in particular potential host communities must be provided with the information that they require to make informed decisions and be confident that the process is open, transparent and legitimate. A wide range of criteria are involved in selecting a preferred site, including impacts of development and operation on the natural environment and landscape, impacts on any specially designated natural or archaeological features, impacts on the human environment especially the transport infrastructure, impacts on socio-economic conditions, and costs. Whereas these might be required to be evaluated to an unusually high standard in the case of a GDF, these criteria and their evaluation are familiar in many major civil engineering projects. There is scope in investigating the best means of making the relevant information accessible to stakeholders, for example by means of on-line geographical information systems.

Although by no means the only selection criterion, the main focus of the JP in this area concerns the geological conditions at potential sites. At the initial stages of a site selection process it is unlikely that detailed information will be available on the geology at GDF depth such that the process has to progress with a recognised level of uncertainty. At these early stages it is valuable to identify the relevant national geoscience database, giving the already-known characteristics of the geology at depth, and to develop methods to make this information accessible to stakeholders. At the outset of evaluating geology, it is usually necessary to identify exclusion criteria in an open and transparent manner. Exclusion criteria are likely to include the presence of exploitable mineral or hydrocarbon resources, the existence of significant geological instability such as seismically active zones or volcanism, the existence of unfavourable hydrogeological activity such as thermal springs or karstification (dissolving of minerals such as limestone),or the existence of large-scale hydraulic features such as large fracture zones. Particularly for this last criterion the implementing organisation needs to use survey methods such as aeromagnetic surveying and classical surveys of rock outcrops and to build confidence that the relevant features can be detected and a potential siting area eliminated if necessary. Generally there is much good practice that can be shared.

Detailed site investigation

At some point in the site selection process when the number of potential sites has been narrowed down sufficiently, it becomes necessary to conduct more detailed geological investigations with the aim of establishing whether a GDF can be developed, meeting the required levels of safety and security, at one or more of the remaining sites and possibly to support the identification of a preferred site. There is considerable overlap with Theme 4 (Site characterisation) at this stage but in this Theme 6 the focus is on developing and improving methods that support the decision-making process. Good practice in advanced programmes has shown the benefit of developing what is termed a site-descriptive model (SDM) at the same level of detail for each of the sites undergoing detailed geological investigation. The SDM captures the key results and conclusions of the investigations in a relatively short report that makes the relevant information accessible to stakeholders and provides a traceable audit trail to the relevant underlying technical reports. There is scope for investigating how best to develop and present the SDM. A further valuable development is to present a

"confidence assessment" recognising that there remain residual uncertainties and discussing whether these uncertainties should prevent progressing to the next stage, i.e. further investigations from the surface, going underground to obtain more detailed information that is inaccessible from the surface, or if appropriate moving directly to develop the GDF. In the case of going underground to undertake more detailed investigations, there is useful guidance available on this step (See, NEA – Underground Testing, and Underground Research Facilities).

As site investigations proceed there is a need to develop and refine the layout and design of the prospective GDF to take account of the developing knowledge of the geology at depth. There is considerable overlap with Theme 5 (GDF design) but in this Theme 6 the focus is on developing approaches to demonstrating optimisation in the prospective exploitation of the site. Important aspects are likely to include selection of the optimal depth for the disposal tunnels/ rooms, determination of spacings of disposal tunnels/ rooms and spacings between waste packages, development of exclusion criteria to apply at specific disposal locations, and the relationship of the underground excavations to the surface waste receipt facilities and the means of access to the underground, classically whether by inclined drift tunnel or vertical shafts – or a combination.

Licensing

It has to be recognised that the formalities of licensing and the number of licensing steps will vary considerably between member states. In some countries a single regulator is largely responsible for the various stages of GDF implementation whereas in other countries a large number of regulators can be involved over the different stages, including those responsible for land-use planning, mining, radiological protection (of both public and workers), transport, long-term safety, security and safeguards. Licence applications will have to be tailored to match these arrangements and there will be no single best practice in this regard. However there is scope for developing and improving the information and argumentation in support of licence applications, particularly in respect of long-term, post-closure safety. There has been a significant reduction in the reliance once placed on numerical modelling results and a corresponding increase in the use of more qualitative arguments alongside evidence of the level of understanding of physical processes. More specifically regulators and stakeholders need to have confidence that, at a given stage of implementation, the residual uncertainties have been identified and that sufficient evidence has been presented to justify progressing to the next stage of implementation. There is scope for developing and improving approaches to this aspect.

Although a distant prospect for even the most advanced member state programmes, it is envisaged that an application will eventually be made for the withdrawal of regulatory control of the operator of a GDF site and pass the responsibility of institutional control to the state once all the relevant wastes have been emplaced. Whereas it would not represent a good use of resources at present to study such an application in detail, it would be valuable at this stage to understand any technical aspects that may be required to be in place from the early stages of implementation to support such an application in the future.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[8]:

Scientific Theme 6: Siting and licensing	• **Maintaining and developing understanding of tools and techniques for developing site descriptive models.** - 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 (J1.6.5/High). - Cooperation and relevant past projects: ?
	• **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 (J1.6.2/Medium). - Cooperation and relevant past projects: ?

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 6: Siting and licensing

Methodologies for site uncertainty treatment: To develop and document best practice guidance to support site selection processes, recognising the uncertainty inevitable present due to a lack of detailed site characterisation data (J3.1).
Site selection process: To develop a process reflecting best practice when deciding upon siting for geological disposal (J3.3).
Technical and socio-political siting criteria: To examine the technical and socio-political criteria on which a partial or full closure of the disposal facility could be decided. To identify the conditions required to implement the decision-making process based on criteria, in terms of technical means (surveillance strategy and methods), pluralist expertise and governance scheme involving the various stakeholders (J3.4).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 6:

Siting and licensing of facilities are typically very specific to national and political considerations, often involving local communities and technical work in support of addressing needs that are site-specific. Thus at present there are no dedicated 'technical' or 'scientific' work packages envisaged that related to this Theme in the first phase of the Joint Programme. Within the Joint Programme Work Package on Uncertainty Treatment (further described in Theme 7), methodologies for site uncertainty treatment will be explored.

Theme 7: Performance assessment, safety case development and safety analyses

Introduction and background:

Integration of safety-related information

[8] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

Prior to construction, and throughout successive phases, most disposal programmes are centred around key milestones and regulatory licencing to demonstrate safety. This includes transport, construction, operational and post-closure safety for the very long-term of the disposal facility. There are well-established existing international networks, NEA/OECD and IAEA guidance to support programmes in their preparation of safety cases and supporting analyses, in addition to state-of-the-art examples from advanced disposal programmes (See, IAEA Safety Standards Series SSG-23). A safety case is a set of statements concerning the safety of the disposal, substantiated by a structured collection of both quantitative and qualitative arguments and evidence. The development of the safety case and the task of integrating of all the necessary information will always be specific to the system evaluated and thus, in this area, each country has to develop its own capabilities in interaction with its local stakeholders, however, there is added value with seeking the help of experienced experts from elsewhere and adopting international good practice with respect to safety case methodologies. The safety case needs to be updated regularly by improved treatment of process understanding and refinement of modelling capabilities, particularly with respect to upscaling and coupling of processes during the post-closure phase but as well for safety during the operational phase.

Performance assessment and system models

To evaluate the long-term evolution of all disposal facility components, a sufficient understanding of coupled thermal-hydro-mechanical and chemical (THMC) processes is needed. Further improvements identified include: Component material descriptions and their degradation during storage periods, together with understanding of post-closure evolution descriptions, particularly the transition from the non-saturated system to fully saturated one; The potential development of microorganisms which can catalyse certain chemical reactions; The variation of redox conditions, including the impact of substances released from waste packages ; The thermo-hydro-mechanical behaviour of the rock and, in particular, the evolution of the damaged zone is of interest; Gas generation and identification of transfer pathways; Water saturation and swelling of bentonite used for backfill, plugs and seals; and Thermal evolution of the host rock and engineered barriers.

One of the challenges is to describe all of the couplings between those processes and to identify those most relevant both for performance and safety assessment. Modelling long-term THMC performance of the host rock, Excavated Disturbed Zone, bentonites, or disposal system components is usually done by means of a spatial and temporal finite element analysis. Upscaling of THMC models in time and space and the study of its validity and representativeness at all scales, constitutes a large field of research. This will combine both numerical developments and experimental work to confirm the choices in terms of representative volumes. This includes the representation of THMC parameters which could exhibit, in some cases, a significant natural variability.

Understanding of physio-chemical processes affecting the evolution of disposal components and geological systems, and their consequences on radionuclide transfer, is based on both an experimental approach and the use of predictive modelling at different temporal and spatial scales. Relevance of modelling and numerical simulation is strongly linked to the development of tools able to represent complex systems in terms of processes and geometry over large time and space scales. Thus, the complexity of some

mechanisms, strong multiple couplings, multi-scale approaches, complexity of objects and heterogeneities to be simulated, management of uncertainties to identify key parameters, and integrated systems are all potential areas for RD&D in order to improve the understanding of disposal systems, and increase robustness in performance and safety assessment applications. In this field, some particular topics that would benefit from further development include multi-scale approaches from the atomic scale (< nm) to the scale of the geological formation (> 100 m) in order to validate relevant phenomena and input data utilizing homogenization and up-scaling techniques.

Management of heterogeneity at all scales, such as natural variability of properties, anisotropy, singularities (fractures, fissures network), non-porous materials and voids, and numerical techniques which allow such heterogeneities to be taken into account are of continued interest. Development of multiple-process modelling, including development of algorithms and numerical methods for strong couplings at the large scale continues. Capability gaps exist in two-phase flow, reactive transport modelling and THMC couplings. Development / improvement (performance, accuracy, robustness) of tools in the area of high performance computing, as applied to system modelling, with numerical resolution methods allowing representation of complex integrated and heterogeneous systems is also of interest.

Treatment of uncertainties

Management and treatment of uncertainties (epistemic, aleatoric) in process understanding, in complex models as well as in its safety implications both for the long term and the operational phase is a continuous activity, in order to identify the key input data of the integrated system, to identify priorities or research and as well to gain confidence in a repository project among stakeholders.

As advanced programmes move close to implementation, consideration of the safety case and its ongoing management and development during construction and operations has become of interest. Linked closely to the implementers management system, understanding of deviations in planned implementation scenarios and pre-closure disturbances, and their effect on performance assessment outputs, safety implications and design adaptation is of continued interest.

RD&D Priorities and Activities of Common Interest to be addressed by the JP[9]:

Scientific Theme 7: Performance assessment,	• **Improved understanding and models for the impact of THMC on the behaviour of the host rock and the buffer materials.** - 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

[9] Numbering scheme is taken over from EC JOPRAD Project, See Annex II. A JP numbering scheme will be implemented in the future

safety case development and safety analyses	during the transition from the non-saturated period to saturation following closure (J2.2.1/High). - Cooperation and relevant past projects: EC project BENCHPAR, HE (Heater Experiment).
	• **Improved understanding of the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space.** - Expected outcomes and impact: To extend deterministic and/or stochastic approaches to take into account the upscaling aspects regarding THM parameters (J2.2.4/High) - Cooperation and relevant past projects: ?
	• **Improved multi-scale reactive transport models.** - Expected outcomes and impact: To further develop the capability to model the migration of contaminants from the repository to the biosphere (J2.3.4/High). - Cooperation and relevant past projects: ?
	• **Further develop transparent and quality assured thermodynamic databases for use in performance assessments and supporting models.** - Expected outcomes and impact: Improved thermodynamic data for key radionuclides, principal elements of the disposal system, secondary phases and solid solutions, filling gaps for specific environments and using natural analogues to assess slow kinetic constraints (metastability). Thermodynamic data may be required in order to validate predictions at higher temperatures and salinity, and to underpin models considering cement phases, alkaline conditions, redox, etc. Improved treatment of uncertainty in thermodynamic data is also anticipated (J1.5.1/High). - Cooperation and relevant past projects: NEA TDB Project, Thermochimie (WMOs: ANDRA, RWM, Ondraf)
	• **Improved understanding of the influence of pre-closure disturbances on long-term safety.** - Expected outcomes and impact: To develop common approaches (including scenarios) for safety case adaptation and update during facility operations and closure (J2.1.1/Medium). - Cooperation and relevant past projects: ?
	• **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) (J2.1.3/Medium). - Cooperation and relevant past projects: ?
	• **Improved performance assessment tools.** - 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 the simulation (sensitivity analysis), and to quantify the effect of uncertainties on these outputs (uncertainty analysis) (J2.3.1/Medium). - Cooperation and relevant past projects: ?

	• **Improve geosphere transport models.** - Expected outcomes and impact: Improved representation of the transport of contamination through the geosphere in support of the safety case (J2.3.3/Medium). - Cooperation and relevant past projects: ?
	• **Improved understanding the role of physical/chemical processes at different scales and linking bottom-up and top-down approaches in performance assessments.** - Expected outcomes and impact: 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.). (J2.3.5/Medium). - Cooperation and relevant past projects: ?
	• **Improved treatment of heterogeneity.** - Expected outcomes and impact: To provide a modelling capability which can integrate available site data to account for heterogeneities in the near field (J2.3.6/Medium). - Cooperation and relevant past projects: ?
	• **Improved computing.** - Expected outcomes and impact: To enable the use of numerical and highly parallelized 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. (J2.3.7/Medium). - Cooperation and relevant past projects: DECOVALEX
	• **Improved understanding for the impact of deviations in planned implementation scenarios on the performance assessment outputs of the disposal facility.** - Expected outcomes and impact: Understanding how deviation (unplanned events) may impact the handover state of the facility as the starting condition for long-term performance assessments. Develop improved scenario treatment and communication of deviations from normal operating scenarios to understand key controls on the performance assessment (J2.1.5/Low). - Cooperation and relevant past projects: ?
	• **Improved understanding of the spatial extent and evolution with time of oxidative transients, as well as the possible impact on safety functions.** - Expected outcomes and impact: To investigate the oxidative transient in the near field during the construction and operational phases, notably with regard to corrosion of metallic components (J2.2.3/Low). - Cooperation and relevant past projects: EC projects BENIPA, NF-PRO, FEBEX
	• **Open-source performance assessment code** - To develop high performance computing oriented code which can simulate multi-phase flow and transport in unsaturated porous media (J2.3.2/Low)

	- Cooperation and relevant past projects: ?
	• **Improve fire and impact assessment** - To assess the impact of fire or explosions on the underground systems during the operational phase (J2.4.1/Low). - Cooperation and relevant past projects: ?
	• **Improve understanding of the impacts of operational safety** - To minimise the disturbance of operations on long-term safety sharing by lessons learned across operating facilities within the nuclear industry and other mining operations (J2.4.3/Low). - Cooperation and relevant past projects: GEOSAF

Enabling Knowledge Management, Strategic Studies and other Cross-cutting Activities Identified of Common Interest that relate to Theme 7: Performance assessment, safety case development, and safety analyses

Assessment methodologies: To continue to share good practice internationally and continue development of advanced methodologies for construction and facility licensing (J2.1.2).
Dose thresholds: To facilitate exchanges on good practice on the development of safety indicators applied in specific safety cases taking into account realistic facility evolution scenarios and time periods. To undertake epidemiological studies of low-dose radiological impacts (J2.1.4).
Use of natural analogues: To verify and build confidence in long-term, large-scale processes, and upscaling of models to repository scale (J2.2.5).
Safety case guidelines, management and review: To evaluate experience from different countries' arrangements for identification of possible gaps or weaknesses in the expertise function's expectations. To develop a common view on areas of significant safety impact and proposals formulated for an appropriate degree of regulatory control (J3.9).
Improve understanding of the impacts of operational safety: To minimise the disturbance of operations on long-term safety sharing by lessons learned across operating facilities within the nuclear industry and other mining operations (J2.4.3).

Ongoing and active work (inc. Horizon 2020 projects) addressing Theme 7:

The European Commission (EC) PAMINA project – Performance Assessment Methodologies in Application to Guide the Development of the Safety Case – was conducted over the period 2006-2009 and brought together 27 organisations from 10 countries. PAMINA had the aim of improving and developing a common understanding of performance assessment (PA) methodologies for disposal concepts for spent fuel and other long-lived radioactive wastes in a range of geological environments. This was followed by a Nuclear Energy Agency (NEA) sponsored project on Methods for Safety Assessment of Geological Disposal Facilities for Radioactive Waste (MeSA).

The Joint Programme first phase includes a number of networking activities to promote knowledge sharing, including a strategic study on understanding of uncertainty, risk and safety from the perspectives of different participants. The objective is to identify precise areas of focus that could be taken forward in future phases of the Joint Programme. The strategic study will develop a common understanding among the different categories of participants (WMOs, TSOs, REs & Civil Society) on uncertainty management and how it relates to risk and safety. In cases where a common understanding is beyond

reach, the objective is to achieve mutual understanding on why views on uncertainties and their management are different for different actors.

4. EURAD - ROADMAP

A **Roadmap**, with clear objectives, linking the Joint Programme activities (as listed in the SRA) to milestones typical of different phases of a radioactive waste management (RWM) programme has been developed (focussed on those planning for disposal). The Roadmap relates to Joint Programme Founding Documents (and was not addressed by the preparatory work carried out in the EC JOPRAD project). It draws from the IAEA work (see, IAEA Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste). The IAEA definitions of recognised phases of a waste disposal programme (and their associated major objectives) are used to provide the Roadmap framework:

- Phase 0: Policy, framework and programme establishment*;
- Phase 1: Site evaluation and site selection;
- Phase 2: Site characterisation;
- Phase 3: Facility construction;
- Phase 4: Facility operation and closure;
- Phase 5: Post-closure.

**Note that Phase 0 was not covered by IAEA-TECDOC-1755, but added to recognise the needs of Members States who are in the process of establishing a waste management programme.*

For each of the phases above, the Joint Programme Roadmap explains how aspects related to, disposal facility design, and safety case development (and supporting safety analyses) span across all phases, including Phase 0. The Roadmap elaborates further on the how the emphasis of work on each of these differs and changes through successive Phases.

The Roadmap demonstrates the totality of scope of the Joint Programme and its relevance to waste management and disposal programmes at different stages of maturity. The Roadmap effectively provides a framework upon which to organise the scientific priorities of the SRA, enabling users and programmes to 'click-in', and to access existing knowledge and active work or future plans. It also provides a framework for future periodic assessment of the Joint Programme, and to evaluate future priorities and new work packages as new knowledge is acquired or as new needs are identified.

The Roadmap comprises 7 tables:

- A theme-specific table showing how identified scope of the EURAD SRA relate to different Phases of implementation and typical Waste Management Programme objectives for each theme (grey boxes).
- The SRA topics/sub-topics within each Theme are flagged ( ) to illustrate those being addressed in-part or in-full by scope of active EC-funded projects, including those of the EURAD 1. Topics/sub-topics that will be addressed in future work of the Joint programme are also flagged ( ).
- RD&D, Knowledge Management and Strategic Studies are each coloured differently.

The Roadmap tables will be used throughout the Joint Programme as a tool to support the management of the SRA in reviewing progress, to support prioritisation of new scope suggestions

(importance and urgency) and communicating completed, ongoing and future work activities to those interested in our work.

Please note that contrary to the request by the EC for the SRA to be translated into a roadmap, with clear objectives, deliverables and high-level milestones for technical solutions per waste streams and waste types, we have intentionally avoided this. Rather we have utilised a work break down structure using themes and IAEA phases (focussed on geological disposal) that combines topics of RD&D relevant to many waste streams and technical solutions. Technical solutions need to be tailored and developed for the specific needs of a national waste management programme, particularly taking account of the waste characteristics and the options for siting. There is no one size fits all technical solution for each waste stream, choices on this remain the responsibility of the national waste management programme.

The IAEA phases used in the roadmap are of a general nature and are each applicable to several waste streams and waste types and include scope on knowledge management to share experiences. The same is also true of SRA themes with the topics / sub-topics where, however, some of the topics have less relevance for the other disposal routes. Furthermore, it is important to recognise that the disposal routes for the other waste streams (lower activity wastes consisting mainly of shorter-lived isotopes) do often not include geological disposal but surface or near-surface disposal. This technology is well established with a number of variants tailored to the specific needs (volumes and exact types of wastes) and boundary conditions (land use planning, etc.) of the respective countries. Depending upon the needs of the Beneficiaries it is suggested that the topic of developing a Roadmap for these types of waste is managed through the Strategic Study on “waste management routes in Europe from cradle to grave” with the support of experts managed by the Programme Office. This may need some modification of that WP in the course of the first year.

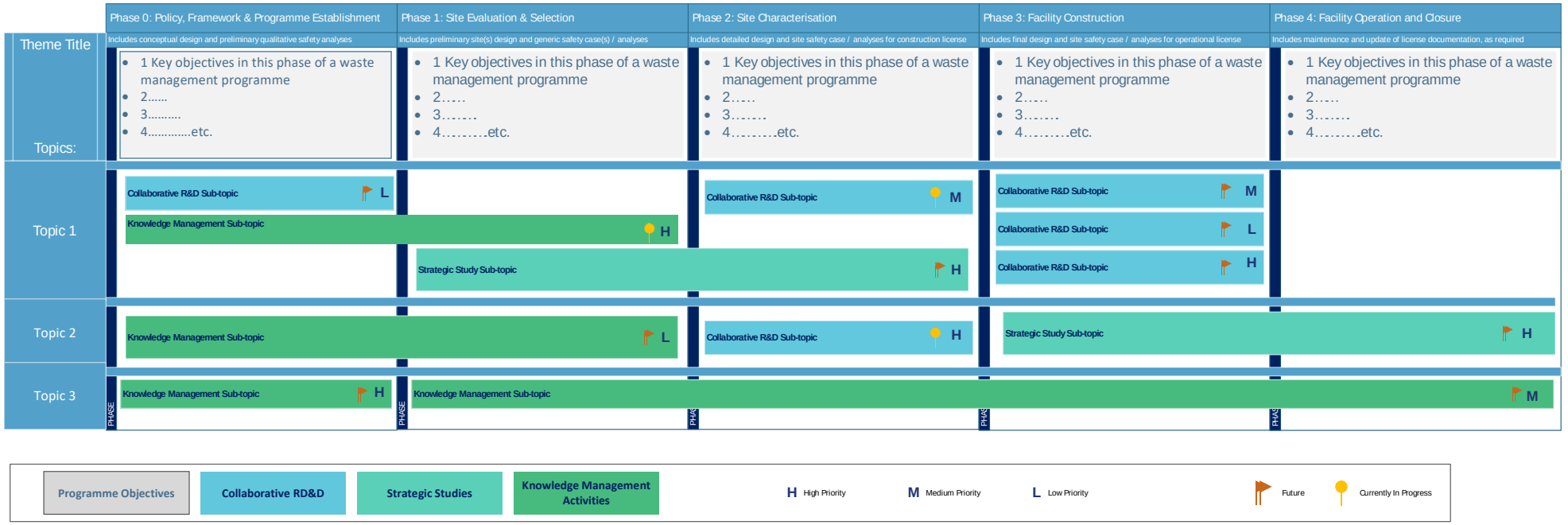
Key to Roadmap Diagrams:

(1) Top Line - Typical Phases of a Waste Management Programme (Phase 0 to Phase 4);

(2) Second Line – Design and Safety Case Focus in each Phase (Conceptual to Site-specific);

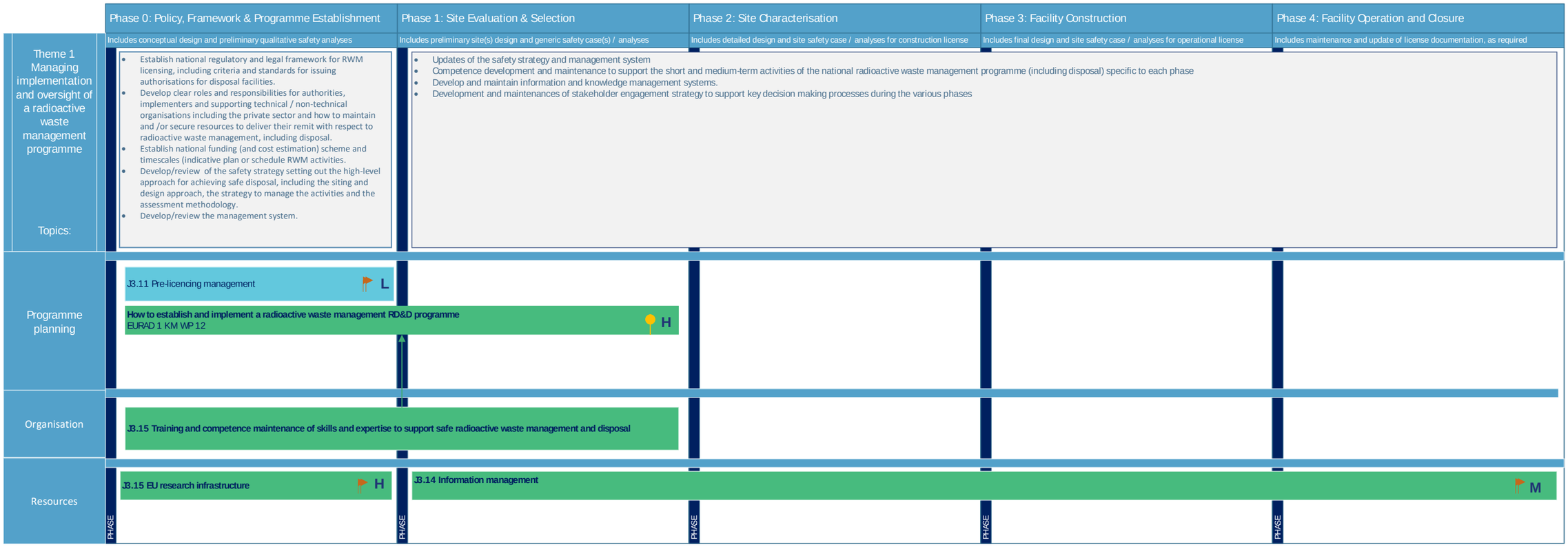
(3) Third Line (light grey boxes) – Typical Programme Objectives (How focus evolves from early stage to advanced-stage focus);

(4) Fourth Line onwards (lines with multi-coloured boxes) - Map of EURAD SRA Topics and Sub-Topics (colour coded according to RD&D, Strategic Studies or Knowledge Management Tasks)



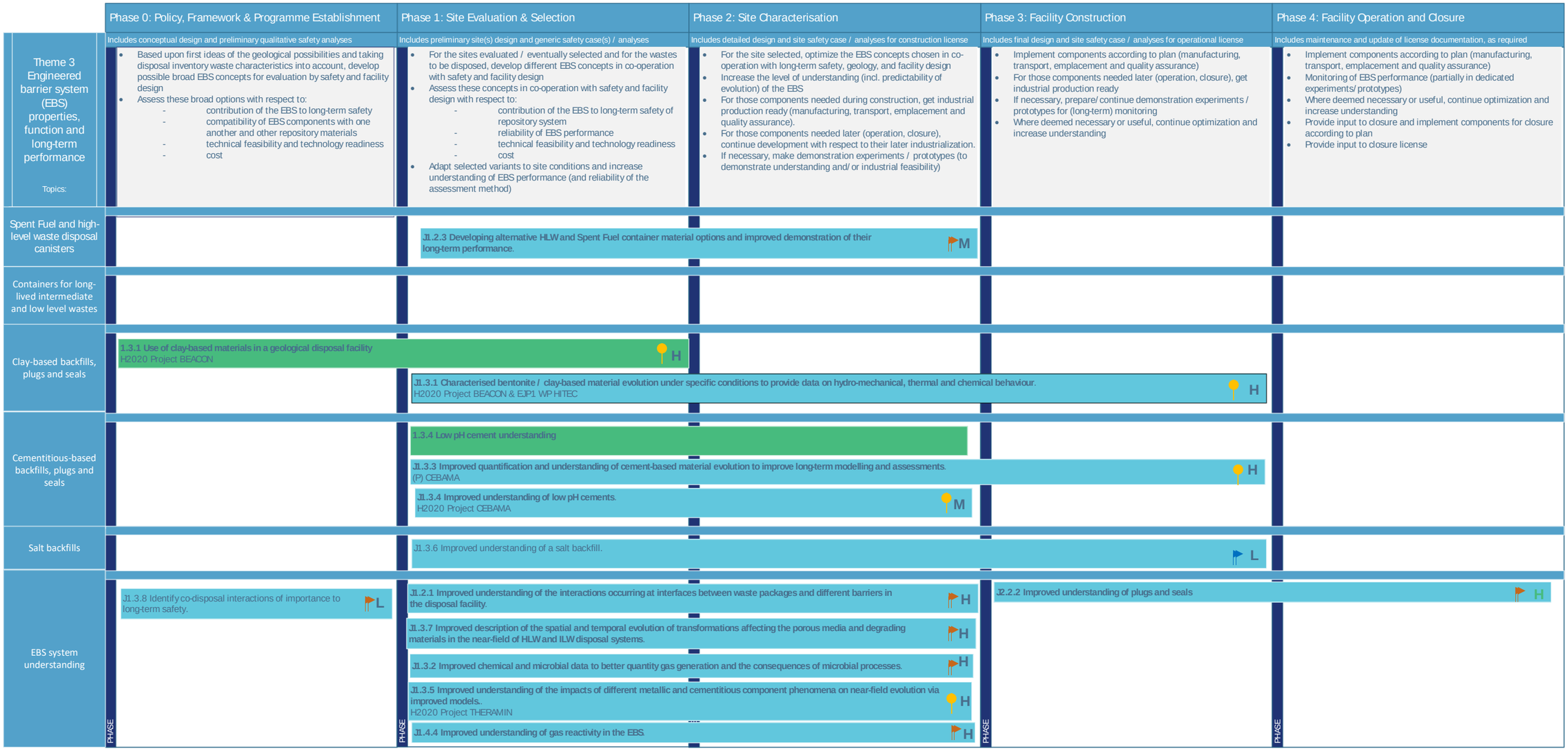
There are a total of 7 roadmap diagrams (as illustrated above), one for each Theme of the EURAD SRA.

Roadmap Theme 1: JP Priorities and Activities of Common Interest that relate to Managing implementation and oversight of a radioactive waste management programme

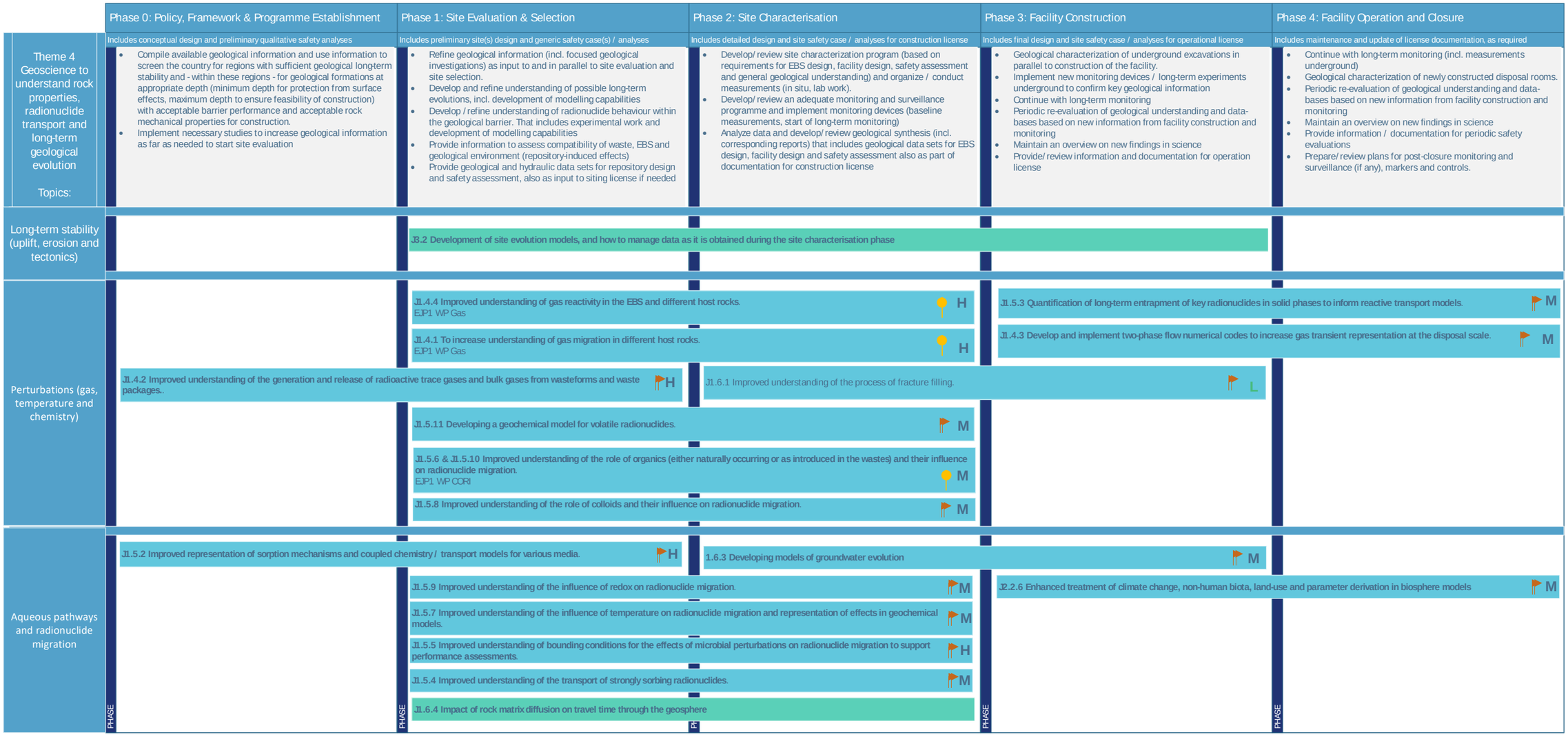


Roadmap Theme 2: JP Priorities and Activities of Common Interest that relate to Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal

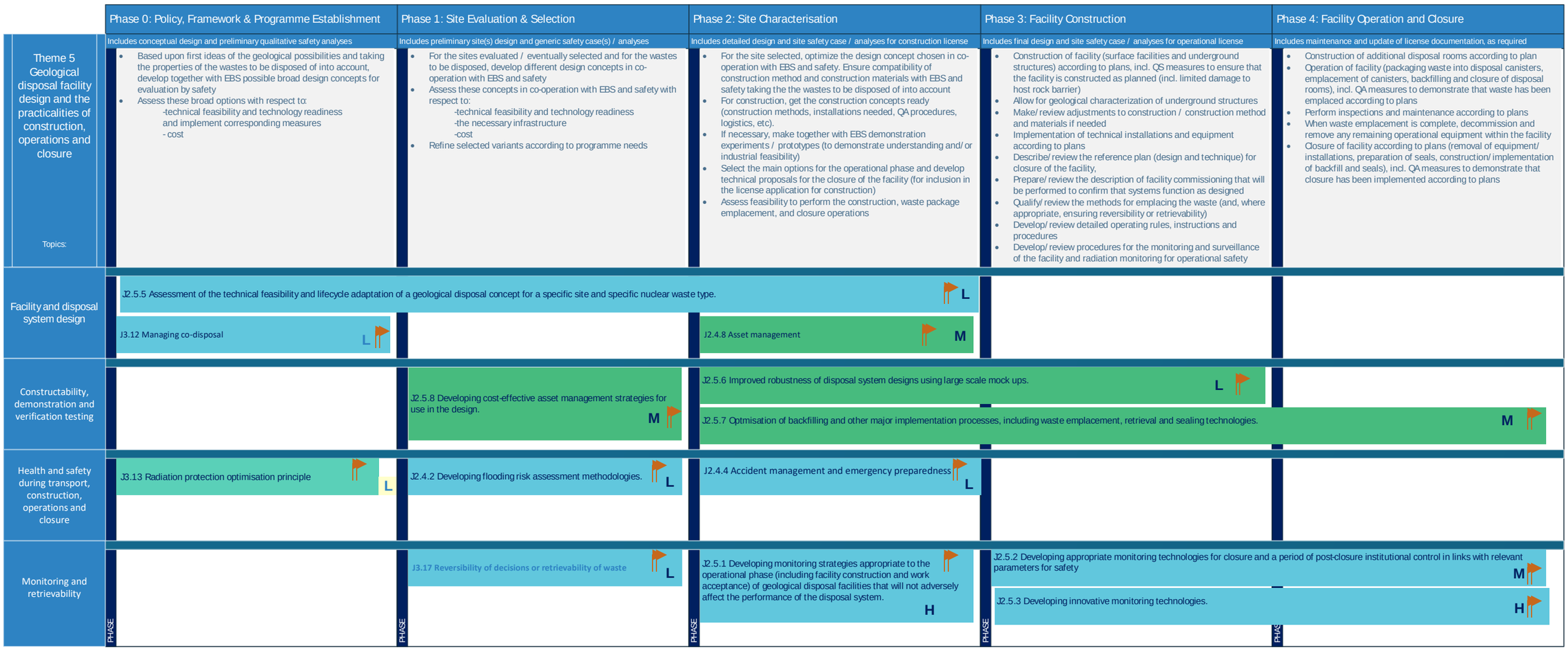
Roadmap Theme 3: JP Priorities and Activities of Common Interest that relate to Engineered barrier system (EBS) properties, function and long-term performance



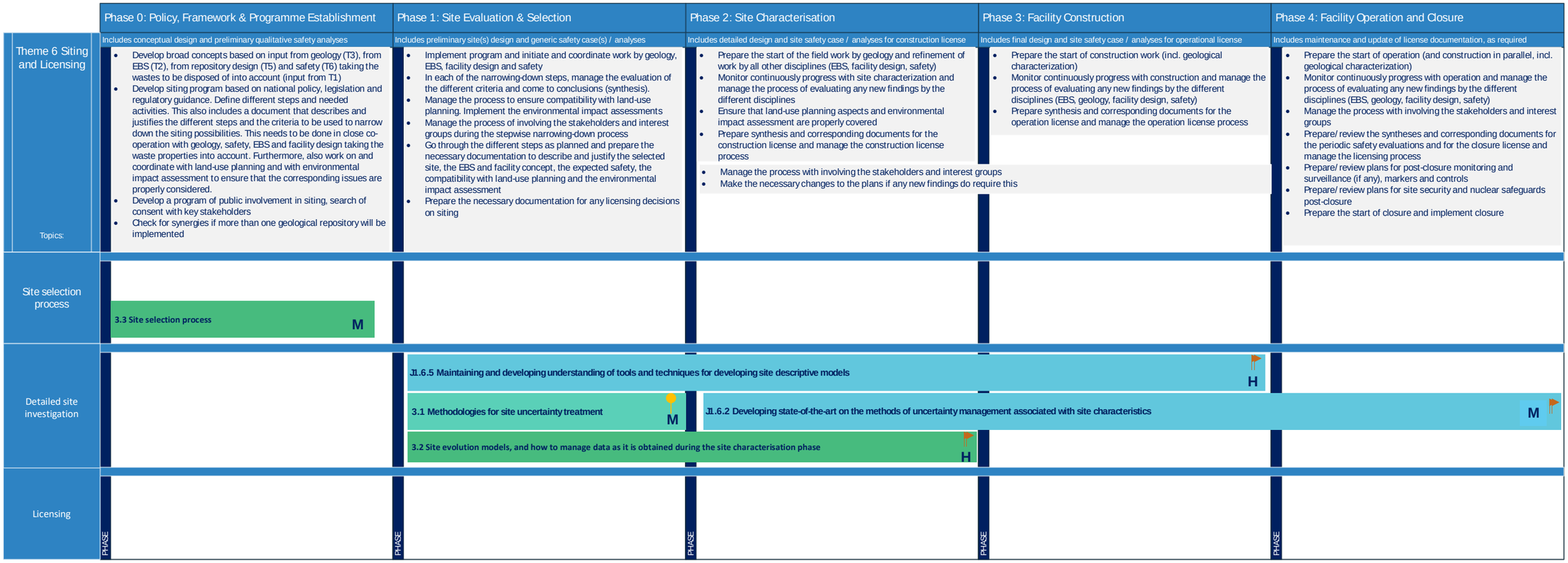
Roadmap Theme 4: JP Priorities and Activities of Common Interest that relate to Geoscience to understand rock properties, radionuclide transport and long-term geological evolution



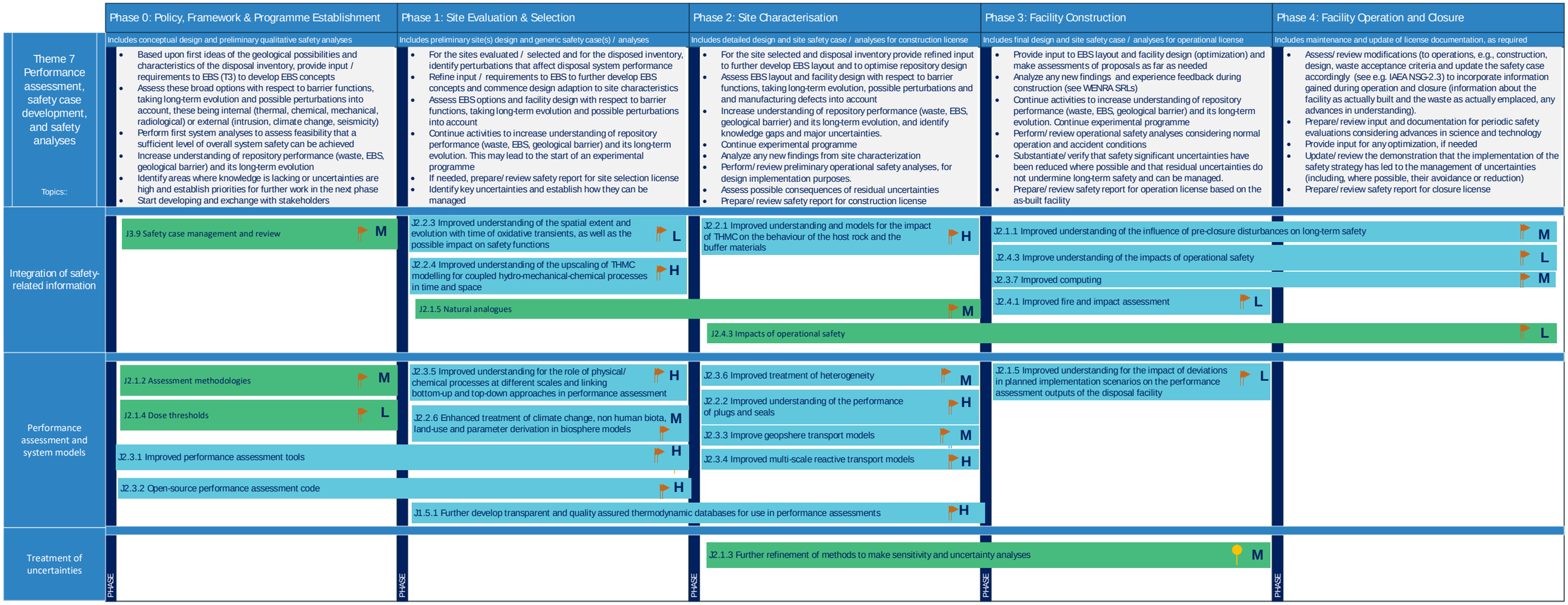
Roadmap Theme 5: JP Priorities and Activities of Common Interest that relate to Geological disposal facility design and the practicalities of implementation



Roadmap Theme 6: JP Priorities and Activities of Common Interest that relate to Siting and Licensing



Roadmap Theme 7: JP Priorities and Activities of Common Interest that relate to Performance assessment, safety case development and safety analyses



5. EURAD – DEPLOYMENT PLAN 2019-2024 (EURAD 1)

Building on the initial preparatory work of the EC JOPRAD project to identify activities of common interest between the Joint Programme contributors and participants, an initial five year deployment plan has been established at inception. The plan adopts a series of Work Packages to organise the activities in a formal work breakdown structure, with scope and participation co-developed throughout 2017/18 in consultation with each of the main JP contributors – the WMOs, the TSOs and the REs (See, Annex 3 - Development of the JP Deployment Plan 2019-2024).

5.1. Framework for the initial Deployment Plan 2019-2024

5.1.1. EURATOM WP2018 Call

Published on October 27th, 2017, the EURATOM WP2018 includes a topic (NFRP-6) to call for the official establishment of the Joint Programme on RWM and its initial implementation phase for 5 years (EURAD 1) (available EC contribution: max 32,5M€). Submission deadline is 27 September 2018. If accepted, EURAD 1 shall be launched mid-2019 for 5 years (2019-2024), after the signature of the Grant Agreement with EC.

The call clearly states that the first implementation phase of the Joint Programme shall be funded by EC through the H2020 *EJP Cofund* instrument. This instrument implies specific provisions for participation rules, as described in the next section.

5.1.2. H2020 European Joint Programme Cofund - Participation rules

In the early phase of JOPRAD and given that the RWM community has already been sufficiently integrated for several years, the option for an internal implementation of activities has been retained, meaning here that the EURAD Beneficiaries are expected to be directly the RD&D actors, and not funding agencies as it is the case in other European Joint Programmes.

Therefore, the participation as **Beneficiary** is limited to organisations having received a mandate by their national programme owner(s) (usually Ministry/regional authority) to participate in the JP implementation phase and that are willing to share the JP Vision/SRA/Roadmap. The mandate shall confirm that organisations are responsible for managing/implementing a RWM programme and/or managing/implementing a RD&D programme needed for implementation as:

- **Waste Management Organisations** (WMOs) whose mission covers the management and disposal of radioactive waste;
- **Technical Support Organisations** (TSOs) carrying out activities aimed at providing the technical and scientific basis for notably supporting the decisions made by a national regulatory body; and
- **Nationally funded Research Entities** (REs) working to different degrees on the challenges of RWM (and sometimes in direct support to implementers) under the responsibility of the Member States.

Beneficiaries can call for **Linked Third Parties** (LTP) to carry out part of the work plan in the Work Packages. A Linked Third Party is an organisation to which a Beneficiary has a pre-existing legal relationship (options are: Memorandum of Understanding, agreement, contract, affiliation, joint research unit…) which is not based on a contract for the purchase of goods works or services.

Other legal entities (such as association) may participate if justified by the nature of the action, in particular entities created to coordinate or integrate transnational research efforts.

Reference documents are the H2020 Participation rules, and the EJP Co-fund Annotated Grant Agreement Model.

5.1.3. H2020 European Joint Programme Cofund rate and form of grant

With a European Joint Programme Cofund, the EURATOM contribution takes the form of a **grant** consisting of reimbursement of total eligible costs related to the implementation of the actions (Work Packages). In EURATOM WP2018, the cofunding rate for the JP on RWM has been set at 55% of total eligible costs. There will be **no cash collection** from the Programme Owners to be put in a "common pot". Therefore, participants (Beneficiaries and Linked Third Parties) shall be able to bear the costs that are not funded by EC, or to find other co-funding sources.

5.1.4. Eligible costs under H2020 European Joint Programme Cofund

Eligible costs are the costs that are necessary to implement the WPs (See Article 6 of the Grant Agreement Model for full details) and that fall under the following categories:

- Direct Personnel costs (unit or actual costs)
- Other Direct costs:
  - Travel
  - Equipment
  - Costs of large research infrastructure
  - Other goods and services
- Indirect costs (flat rate: 25% of direct costs)
- Costs for subcontracting

5.2. Deployment mechanisms

To deliver against the EURAD Vision, SRA and Roadmap, the Work Plan of the Joint Programme implementation phase will be broken down into a set of Work Packages, Tasks and Sub-Tasks. Four different types of Work Package (WP) have been adopted, as well as specific cross-cutting tasks - interactions with Civil Society and providing access to knowledge/results – that will be directly embedded in specific WPs. These are each described below.

5.2.1. RD&D Work Packages

RD&D WPs focus on science, engineering and technology advances that support the generation of new knowledge to progress RWM, including disposal, across Europe. The activities to be carried out are a balance between those with a direct link to operational RD&D (direct links with implementation of deep geological disposal or other waste management route) and prospective RD&D (long-term experiment and/or modelling works to demonstrate the robustness of the waste management concepts and contribute to maintain scientific excellence and competences throughout the stepwise long-term management of radioactive waste).

5.2.2. Strategic Studies Work Packages

Strategic studies WPs are initiated in order to agree upon and define in some detail the needs for future activities, including further specific thematic studies or RD&D at the forefront of science. This may also be referred to as 'think-tank' or networking activities to determine if there is a RD&D need on an emerging issue, if there is a need of a position paper or if it is considered mature and suitable for knowledge management activities. Such studies will enable experts and specialists to network on methodological/strategical issues and advance significant challenges that are common to various national programmes and that are in direct link with scientific and technical issues.

5.2.3. Knowledge Management Work Packages

Knowledge Management is enabled by three permanent WPs that derive directly from EURATOM expectations under WP2018, and that will be implemented through the Annual Work Plan:

- **State of Knowledge** - Activities under this WP consist of developing a systematic approach of preserving/capitalising of and providing open-access to knowledge generated in the field of RWM research. This shall be done on a stepwise basis with first the establishment of the functional structure for identifying and describing knowledge (shall be directly linked to the Roadmap structure).
- **Methodological guidance** - Activities under this WP consist of 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. Such WP shall pursue and complement the work initiated with the PLANDIS Guide.
- **Training/mobility -** Activities under this WP consist of developing a diverse portfolio of tailored basic and specialised training courses for the end-users within EURAD under the umbrella of a "School of Radioactive Waste Management", taking stock of and building upon already existing initiatives (i.e. IAEA and NEA) and creating new initiatives to bridge the identified gaps. This WP will also organise a mobility programme to provide access to dedicated infrastructures associated with the Mandated Actors/Linked Third Parties within EURAD. This work will be carried out in close interaction with European networks having a recognised experience in training/mobility in the field of RWM.

In addition to the three permanent Knowledge Management Work Packages above, there are additional Knowledge Management activities integrated with the RD&D Work Packages, for example, state of art activities.

As emphasised with respect to Methodological Guidance, identified as a priority and clearly underlined in the EURATOM WP2018 call, there is a need to carry out a prioritisation exercise with WMOs, TSOs and REs in order to identify key existing knowledge and target competences that shall be covered in both State-of-Knowledge and Training/Mobility WPs under the EURAD 1 for the target audiences.

Thus, a very first task of both State-of-Knowledge and Training/Mobility WPs (as part of the first Annual Work Plan) shall consist of carrying out this prioritisation of existing knowledge. This will be coordinated by the Programme Management Office. The outputs will be directly integrated into the EURAD Roadmap and will serve as the framework for establishing the State-of-Knowledge and Training/Mobility WPs' Annual Work Plans and also help the evaluation of new RD&D proposals to ensure their relevance and that no duplications will occur. This knowledge management scope will consider the large body of information produced by WMOs over past decades that is in the public domain (in addition to other knowledge sources), and therefore should be considered as complementary to (and not in-conflict with) commercial consultancy services offered by some WMOs.

5.2.4. Programme Management Office Work Package

A WP will be dedicated to the activities of the Programme Management Office (PMO) which is responsible for the proper coordination and implementation of the overall work plan of the JP implementation phase as approved by the General Assembly. The Programme Management Office is in charge of:

- Scientific and technical coordination of the overall programme (RD&D, Strategic Studies, Knowledge Management, Civil Society Interactions);
- Day-to-day management (budget follow-up, reporting exercises…);
- Communication/dissemination activities (Annual JP meetings, Newsletters, website…); and
- Administration of online access tools (Extranet, Knowledge Management platform, EC Grant Agreement system).

5.2.5. Providing access to knowledge – cross cutting component

The investment of so much knowledge capital (both existing knowledge and knowledge generated in the RD&D/Strategic Studies and KM activities of the JP) striving for safer and more efficient RWM also requires equipping decision-makers with the adequate capacities for its access, retrieval, organization and interpretation to support decision making. The knowledge platform to be designed and implemented within the Knowledge Management WP shall be based, among others, on an information architecture that accounts for context, objectives, issues, and solutions. It shall also be based on an application architecture oriented toward problem-solving, on a functional architecture oriented toward cooperation, and on a technical and easy accessible architecture enabling to overview knowledge readiness and development.

5.2.6. Interaction with Civil Society – cross cutting component

One objective of the JP is to allow innovative ways for close interactions between experts from WMOs, TSOs and REs and Civil-Society (CS) Organisations. Model of pluralistic interactions between them has been developed and tested under previous preparatory projects (SITEX-II and JOPRAD). The JP will also benefit from on-going experience in EC projects like BEACON or Modern2020, in order to propose a framework for interaction with CS that aims to contribute:

- Facilitate the translation of scientific/technical results to allow effective interactions with CS;
- Create the conditions for Civil Society Organisations to express their expectations and perspectives;
- Improve the mutual understanding of how and to what extent an RD&D activity on RWM makes sense and contributes to improving decisions;
- Develop propositions on how to interact with CS on scientific and technical results, how to deal with uncertainties (inherently linked to the long timeframes and numerous processes considered for geological disposal), and on how to interact with CS stakeholders in order to promote mutual benefit of the available knowledge, based on cooperation and sharing.

To do so, the EJP has the ambition to establish interaction activities with a group of representatives of civil society (**the CS group**) gathering representatives of local communities having interest in RWM such as local association, local Committee of Information, local partnership (or having participated to such groups), and representatives of European or national CS Organisations willing to take part (as external contributors to the Joint Programme) in interactions with the nationally mandated organisations for RD&D participating in EURAD. The composition of the CSO group will be finalised during the inception phase of the JP according to a selection procedure open to Civil Society applicants from the EU. The CSO group includes several categories of participants such as representatives of European or national Civil Society Organisations, members of local communities having interest in Radioactive Waste Management such as local association, local Committee of Information, local partnership (or having participated to such groups). Each candidate will demonstrate evidence of a standing engagement (of his institution, of himself if individual participant) in the follow-up of RWM

activities (for a period of at least 3 years in the RWM field). Each participant should be willing to attend (at least twice a year) a program of meetings where facilitated interactions with the JP participants will be organised. The expected role of the member of the CSO group in the JP is to provide views and feedback to JP participants on the current achievements and results of a selection of JP Work Packages (both R&D and Strategic Studies WPs), along their development.

The interactions with the CS group will be facilitated by Civil Society experts (**the CS experts**), working for Linked Third Parties to mandated actors in the Joint Programme, having a long-term engagement on RWM and/or having skills/experience on the involvement of Civil Society in scientific and technical issues. The CS experts will interact with the institutional experts from the WMOs, TSOs and REs in order to understand the field of study. The process will make issues explicit for people with less expertise and allows the CS experts to identify general and more specific issues of interest, allowing for a constructive discourse.

For the first wave of the EURAD – phase 1, the following Work Packages have been selected for specific interactions with civil society: SFC RD&D WP; HITEC RD&D WP; ROUTES Strategic Study WP; and UMAN Strategic Study WP. The reasons for selection of these Work Packages are: SFC RD&D deals with SF predisposal issues which is interest for civil society in many nuclear countries, HITEC RD&D represent a continuation of civil society interaction in EU research on the behaviour of clay under repository conditions. Both Strategic Studies (ROUTES and UMAN) are focusing on more generic aspects of RW management and are of interest for civil society in EU countries.

In each selected WP, CS Experts will be involved in different activities of the WP in order to prepare interactions between the CS group and the WP participants along the WP development. The CS experts will work in an organised process together with representatives from WMOs, TSOs and REs in the WP.

For organizational convenience purposes, the work of the CS experts consisting of facilitating the interactions with the CS group is described in a dedicated task or subtask of the selected WPs. This allows having a clear framework for CS interaction activities that is methodologically coherent, regular in time, and easy to coordinate at the EJP level. In close collaboration with the WP Boards (WP Leader and task leaders) the role of CS Experts is to:

- Sketch out and map the key stakes related to the work performed in the different tasks/subtasks of the WPs from a CS point of view in order to facilitate liaison with the broader CS group;
- Following the work performed in the tasks/subtasks of the selected WPs and participate in key working meetings of these tasks;
- Contribute to skill building of the broader CS group by preparing and animating a specific session dedicated to the selected WPs in the CS annual workshop of EURAD (see above).

Furthermore, under the PMO, a dedicated coordination task is established to coordinate, support and integrate at the EJP level all the interactions activities with Civil Society. This coordination task will consist of providing methodological support for CS interactions with RWM stakeholders: elaboration of material, methodologies, processes and sessions to prepare EURAD participants and CS representatives in order facilitate fruitful interactions, as well as the assessment of the on-going experimental model of Interaction between EURAD participants and Civil Society. This coordination work will also consist notably of organizing yearly a workshop involving the participants of the CS group, the CS Experts together with a panel of experts from WMOs, TSOS and REs participants in the EJP.

Deployment Plan Table 1: Deployment Mechanisms to be used by the EURAD

Type of WP	Type of actions	Examples of possible deliverables
Collaborative RD&D WPs	Activities aiming at developing and consolidating scientific and technical knowledge. Activities shall be a balance between those with a direct link to operational RD&D (direct links with implementation of deep geological disposal or other waste management route as well as safety concerns) and prospective RD&D (short and long-term experiment and/or modelling works to demonstrate the robustness of the waste management concepts, to increase understanding and predictability of the impact of fundamental processes and their couplings or to maintain scientific excellence and competences throughout the stepwise long-term management of radioactive waste). In some RD&D WPs, a specific task will be integrated for Interaction with Civil Society.	State-of-the-art (initial and update), S/T deliverables, reports, demonstrator, pilot, prototype, plan designs, software, technical diagram...
Strategic Studies WPs	Actions consisting of enabling experts and specialists to network on methodological/ strategical issues and advance significant challenges that are common to various national programmes and that are in direct link with scientific and technical issues. In some Strategic Studies, a specific task will be integrated for Interaction with Civil Society.	Position paper (e.g. emerging needs for future RD&D/Strategic Studies/KM activities), report on generic methodologies, best practices…
Knowledge Management WPs	Actions consisting of developing State of Knowledge; developing descriptive methodological guidance and developing/delivering Training modules and mobility measure.	State-of-knowledge documents; Guidance documents, Training delivery and materials…
Programme Management Office WP	Scientific and technical coordination/integration of the overall JP (monitoring EURAD progress, day-to-day administrative, financial and legal management, reporting exercises, interactions with EC, communication and dissemination activities, administration of JP website, Extranet, Knowledge Management Platform, Civil Society Interactions).	Management tools, Periodic reports, financial statements, website, platforms…

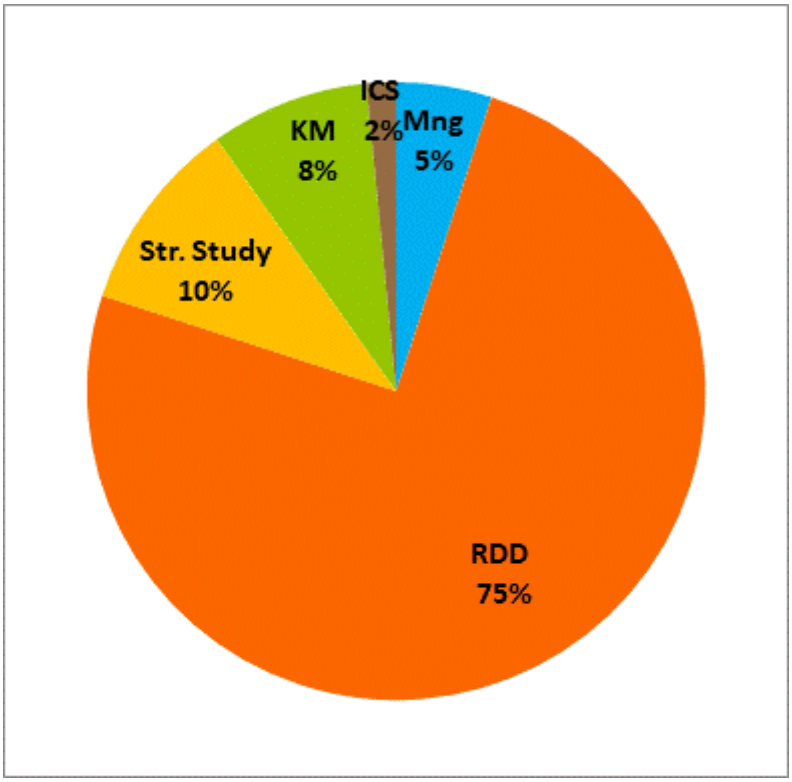
5.3. EURAD 1 – funding and cofunding mechanisms

5.3.1. Indicative distribution of EC funding between the different type of activities

The indicative distribution of EC funding between the different types of activities for the first 5 years of the Joint programme (EURAD 1) has been set as follows:

- 75% of the EC funding will be dedicated to RD&D WPs;
- 10% of the EC funding will be dedicated to Strategic Studies WPs;
- 8% of the EC funding will be dedicated to Knowledge Management WPs;
- 2% of the EC funding will be dedicated to Interaction with Civil Society Organisations;
- 5% of the EC funding will be dedicated to Programme Management and Dissemination.

Deployment Plan Figure *5.* : Distribution of EC funding between the different activities of the EURAD (KM=Knowledge Management, ICS=Interactions with Civil Society, Str.Study-Strategic Studies, RDD-RD&D, and Mng- Joint Programme Management and Administration)



*ICS – This reflects total Interaction with Civil Society budget, which during implementation is integrated across RD&D, Str. Study and Management.

** KM – This reflects total standalone Knowledge Management activities handled by the Knowledge Management Work Packages. This figure is higher (in reality) as there are additional Knowledge Management Activities, such as state of the art reports, undertaken and integrated within the RD&D and Str. Study Work Packages.

5.3.2. Internal funding rates for each type of activity

EC will reimburse 55% of the total eligible costs that are necessary to implement the Work Plan. The consortium is free to redistribute EC co-funding as it decides it, i.e. internal funding rates can be set for different types of activities.

The following funding rates have been established for EURAD 1:

Type of WP	Indicative internal rate
Collaborative RD&D	50 %
Strategic Studies	~70 % (it will be adjusted so that RD&D funding rate does not go under 50%)
Knowledge Management	
Interaction with Civil Society	
Programme Management Office	100 %

5.3.3. Flexibility mechanisms

According to the EC, the EURAD must remain flexible to **include new activities** in order to be as needs-driven as possible; and to **integrate new organisations** that would be mandated after the submission of the proposal or during the course of an implementation phase.

For RD&D WPs, the principles of flexibility is implemented as follows: about 70% of the RD&D budget shall be allocated to WPs/tasks that will start at Month 1 of EURAD 1. The remaining 30% shall be allocated to WPs/tasks that will be approved by the EURAD Consortium (General Assembly) during year 2 and start at Month 24 (for a maximum duration of 36 months).

For Strategic Studies WPs, the principles of flexibility are implemented as follows: about 70% of the budget for Strategic Studies shall be allocated to WPs/tasks that will start at Month 1 of EURAD 1. The remaining 30% shall be allocated to WPs/tasks that will be approved by the EURAD 1 Consortium (General Assembly) and that will start from Month 24 (for a maximum duration of 36 months.

Proposals for new RD&D and Strategic Studies WPs will emerge as the Joint Programme progresses, these will be considered in an open and transparent manner via the PMO and GA. The EURAD Roadmap will support this by providing the framework for performing a structured gap analysis. A technical coordinator will be appointed and will take the lead of the proposal development. When ready, the WP will be reviewed and approved by the General Assembly, if approved, it will be included in EURAD 1 and will start at Year 3.

For Knowledge Management, the principle of flexibility is ensured by a yearly allocation of KM budget. About 20% of the KM budget will be allocated to tasks that will be implemented in the first year. The KM budget will be then allocated on an annual basis.

5.4. EURAD 1 - Work Packages

For the 2019-2024 plan, the following Work Packages have been initiated:

Programme Management Work Package - permanent:

- WP1 - Project Management Office including Dissemination

RD&D Work Packages – 1st wave:

- WP2 - Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED);
- WP3 - Cement-Organic-Radionuclide interactions (CORI);
- WP4 - Development and Improvement Of Numerical methods and Tools for modelling coupled processes (DONUT);
- WP5 - Fundamental understanding of radionuclide retention (FUTURE).
- WP6 - Mechanistic understanding of gas transport in clay materials (GAS);
- WP7 - Influence of temperature on clay-based material behaviour (HITEC); and
- WP8 - Spent Fuel characterisation and evolution until disposal (SFC).

Strategic Studies Work Packages – 1st wave:

- WP9 - Waste Management routes in Europe from cradle to grave (ROUTES); and
- WP10 - Understanding of uncertainty, risk and safety (UMAN).

Knowledge Management Work Packages - permanent:

- WP11 - State of Knowledge (SoK);
- WP12 - Guidance; and
- WP13 - Training / Mobility.

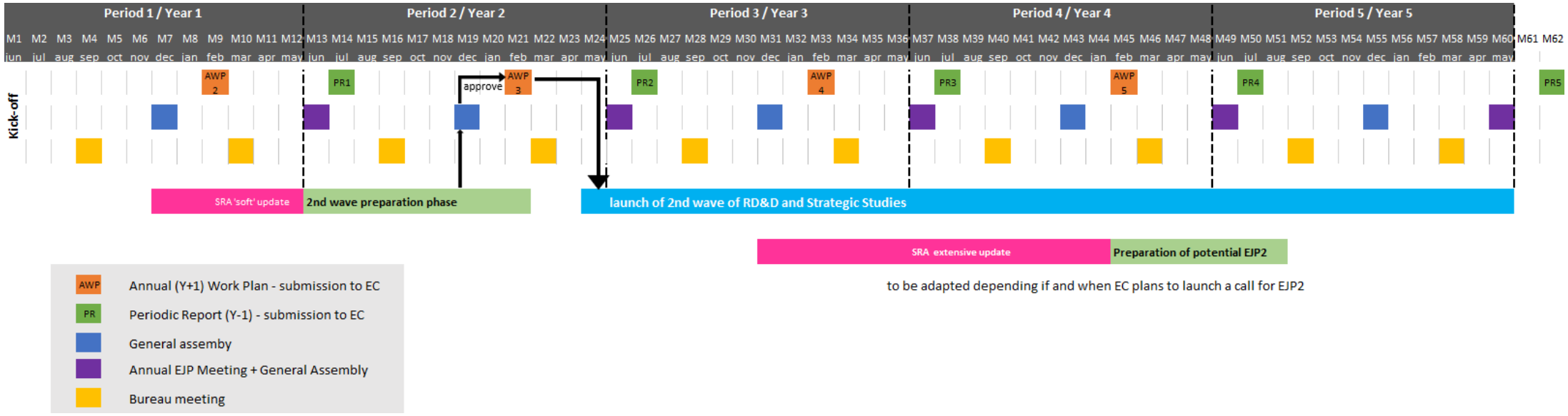
5.5. Update of the SRA/Roadmap during EURAD 1

During the EURAD implementation phase 1, we plan a **'soft' update** of the SRA/Roadmap between Month 9 and Month 12 in view of the preparation of the 2nd wave of RD&D and Strategic Studies WPs where it is anticipated that minor edits and additions should be made, e.g. assessing the level of common interest of topics that emerged when developing the SRA and that were not included in JOPRAD Programme Document; identification of emerging R&D needs and assess level of common interest if any.

We anticipate an **extensive update** of the SRA/Roadmap at Year 4 (exact timing to be adjusted in order to be in line with Euratom work programme) to coincide with preparation and prioritisation of the scope of the potential EURAD 2. During this extensive update, it is anticipated that significant changes may result to take account of learning from EURAD 1 and align the Vision, SRA, Roadmap and Work Package scope and methodologies with how things evolve, particularly with respect to the JP governance scheme and how the criteria used to identify needs of the WMOs, TSOs and REs.

The figure below provides an indicative overview of these important milestones (soft/extensive updates of the SRA/Roadmap), as well as all milestones for the programme coordination .

Figure 6. Indicative Milestones of the EURAD 1



EUROPEAN JOINT PROGRAMME ON RADIOACTIVE WASTE MANAGEMENT (EURAD)								
Identifier No.	EURAD 1 Work Packages (2019-2024)	Indicative Budget	EURAD Strategic Research Objectives	EURAD Beneficiaries				
		Total Cost (EC + Beneficiary Contributions)	How the Work Package will address objectives, priorities and activities of high common interest in the EURAD Strategic Research Agenda	WMOs	TSOs	REs	Civil Society	Coordinator
				◆ = Beneficiary Organisation; ◆ = Coordinating Beneficiary Organisation				
	Programme Management Office	**7%**						
WP1	Administration, Scientific Coordination, Communication and Dissemination	€2.7 M		◆◆	◆	◆◆	◆	ANDRA (France)
	Collaborative RD&D	**75%**						
WP2	Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED)	€5.1 M	Multiscale approach and process integration to improve long-term modelling and assessments .	◆◆◆◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆		SCK-CEN (Belgium)
WP3	Cement-Organics-Radionuclide-Interactions (CORI)	€4.7 M	Improved understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration in cement based environments.	◆◆	◆◆◆	◆◆◆◆◆◆◆◆		KIT (Germany)
WP4	Development and Improvement of Numerical Methods and Tools for Modelling Coupled Processes (DONUT)	€3.7 M	Improved understanding of the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space.	◆◆◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆		ANDRA (BRGM - France)
WP5	Fundamental Understanding of Radionuclide Retention (FUTURE)	€4.6 M	Quantification of long-term entrapment of key radionuclides in solid phases to inform reactive transport models and the influence of redox.	◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆		FZJ (Germany)
WP6	Mechanistic Understanding of Gas Transport in Clay Materials (GAS)	€5.6 M	To increase understanding and predictability of gas migration in different host rocks.	◆◆◆◆◆◆◆	◆◆◆	◆◆◆◆◆◆◆◆		ONDRAF/NIRAS (Belgium)
WP7	Influence of Temperature on Clay-based Material Behaviour (HITEC)	€5.3 M	Improved THM description of clay based materials at elevated temperatures.	◆◆◆◆◆◆◆◆◆◆	◆◆	◆◆◆◆◆◆	◆	VTT (Finland)
WP8	Spent Fuel Characterisation and Evolution Until Disposal (SFC)	€5.8 M	Reduce uncertainties in spent fuel properties in predisposal phase.	◆◆◆◆◆	◆◆◆◆◆	◆◆◆◆◆◆◆◆◆◆	◆	SKB (Sweden)
	Strategic Studies to Address Complex Issues and Expert Networking	**10%**						
WP9	Waste management routes in Europe from cradle to grave (ROUTES)	€1.7 M	Waste Management Routes across Europe considering different waste types and their specified endpoints.	◆◆◆◆◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆◆◆◆	◆	IRSN (France)
WP10	Uncertainty Management multi-Actor Network (UMAN)	€1.7 M	Further refinement of methods to make sensitivity and uncertainty analyses and the development of a multi-actor network for uncertainty management.	◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆◆	◆◆◆◆◆◆◆◆	◆	BelV (Belgium)
	Knowledge Management	**8%**						
WP11	KM State-of-Knowledge (SoK)	€1.4 M	To maintain information, knowledge and records over the long lead- and implementation-timelines of geological disposal programmes, from pre-licensing through to the post-operational phase.	◆◆	◆◆	◆◆	◆	BGE (Germany)
WP12	Guidance	€0.5 M	To identify RD&D and knowledge transfer needs in support of defining pre-licensing activities that can support success in the siting and licensing phase/process.	◆◆	◆◆◆		◆	SURAO (Czech Republic)
WP13	Training & Mobility	€0.6 M	Training and competence maintenance of skills and expertise to support safe radioactive waste management including disposal.	◆◆	◆◆◆	◆◆	◆	SCK-CEN (Belgium)

Table 1. Overview of EURAD 1 Work Packages (2019-2024)

6. EURAD – GOVERNANCE & EVALUATION

The overall organisation of the EURAD can be seen in the Figure below.

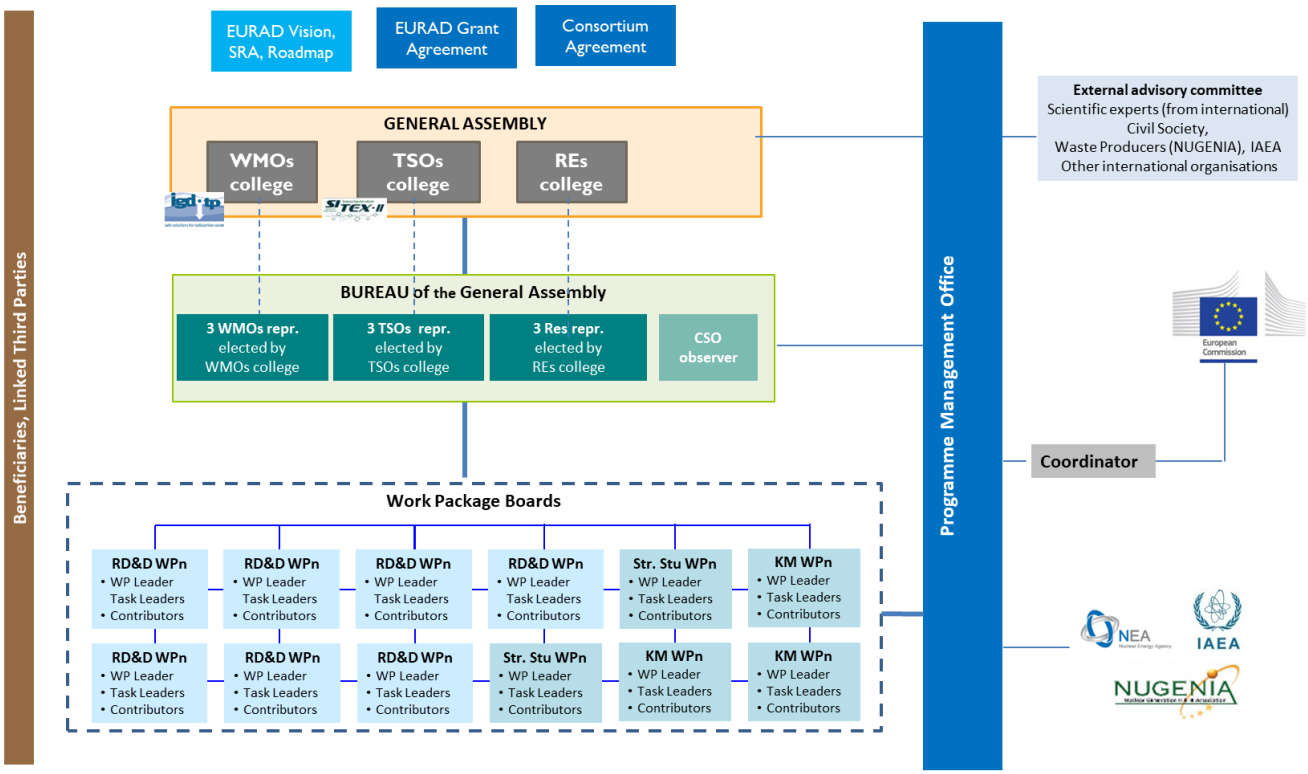


Figure 7*:* Governance & Evaluation - Overall Organisation of the EURAD

6.1. Governance

The **General Assembly** is the ultimate decision-making body of the EURAD consortium. It is responsible for agreeing the strategy of the EURAD in line with the content of the SRA/Roadmap and the Euratom Work Programme. It is composed of one representative of each Beneficiary (Mandated organisations). Beneficiaries fall into one of the three following categories: Waste Management Organisations (WMOs), Technical Support Organisations (TSOs) and Research Entities (REs). Each category has its own **college** within the General Assembly: WMOs college, TSOs college and REs college[10].

The General Assembly shall be free to act on its own initiative to formulate proposals and take decisions, following preview with the Bureau and/or Programme Management Office[11]. In addition,

[10] The establishment of the colleges is meant to be compatible with the boundary conditions of independence (Maintenance of Independence principle) between the "expertise function" (fulfilled by TSOs and by some Research Entities) and the "implementer function" (fulfilled by WMOs). It shall allow verification that the positions/decisions of the GA are inclusive in terms of actors (Inclusiveness principle).

[11] All individual proposals are made to the Programme Management Office in the first instance, and then directed up the reporting chain if it requires either technical or wider oversight. First to the Bureau, and then second to the General Assembly. Any items taken to the General Assembly must have been discussed with the PMO and sponsored for wider discussion by the Bureau.

proposals made by the Bureau and by the Programme Management Office shall be considered and decided upon by the General Assembly.

The General Assembly shall meet regularly (at least twice a year).The members of the Bureau and the PMO shall also participate in the General Assembly meetings. It is anticipated that the CSO observer of the Bureau and the WP Leaders shall be invited as observers, however the General Assembly reserves the right to call closed meetings, if required.

Terms of Reference of the General Assembly can be seen in Annex 1.

The General Assembly shall establish a Bureau. The Bureau is accountable to the General Assembly. It proposes documents and decisions to be taken by the General Assembly. It acts on behalf of the General Assembly in close interactions with the Programme Management Office during the elaboration of proposals, for subsequent decision by the General Assembly. The Bureau shall be composed of a total of ten representatives; 3 elected by each General Assembly college together with one CSO representative as observer.

- The WMOs College elects its three Bureau representatives (including one representative from a country with early stage/ small RWM programme).
- The TSOs College elects its three Bureau representatives (including one representative from a country with early stage/small RWM programme).
- The REs College elects its three Bureau representatives (including one representative from a country with early stage/small RWM programme).
- The CSO observer (elected by the CSOs) .

The Bureau members shall represent the interest of their respective community and not the interest of their own organisation or country. The composition of the Bureau shall be regularly reviewed/re-elected for suitability of roles, responsibilities and membership (at least by mid-term of the first 5-year implementation). This shall be done through consultation with each of the Colleges and any changes approved by the General Assembly.

Terms of Reference of the Bureau of the General Assembly can be seen in Annex 1.

The **Programme Management Office** (PMO) is in charge of scientific and technical coordination of the implementation of the programme, as well as the day-to-day management and communication activities. It is responsible to the General Assembly for the overall top-level planning, coordination and implementation of the EURAD Work Plan in line with the strategy agreed by the General Assembly. It interacts with the EC and key stakeholders: national programmes, international organisations/ programmes, Civil Society Organisations, science/policy interface.

The PMO is housed in the premises of the Coordinator which is the legal entity acting as the intermediary between the Parties and the European Commission, and to which staff from Beneficiaries can be seconded (via requests made to the PMO office and approved by the General Assembly). The PMO shall organise regular meetings (at least four a year) gathering all the WP Leaders to ensure interactions between the projects and ensuring joint programming of activities.

Terms of Reference of the PMO and the Coordinator can be seen in Annex 1.

For each technical Work Package a **Work Package (WP) Board** is set-up. It is composed of the Work Package Leader and the task leaders. The WP Board ensures that the WP is progressing according to the agreed specifications, milestones and planning. The WP Board is also responsible for reporting the

work progress, any WP deliverables and eventual modifications of the WP work plan to the Programme Management Office.

Terms of Reference of Work Package Board can be seen in Annex 1.

External advisory board (EAB) advises the General Assembly on strategic and implementation issues related to the EURAD and its coherence with respect to the Strategic Research Agenda and Vision. The EAB is composed of scientific and technical experts at international level, Civil Society Representatives, IAEA representative, NUGENIA and other potential international organisations.

The EAB shall be invited to the annual meeting and shall provide external advice and recommendations for the implementation of the EURAD.

6.1.1. Conditions for Participation

The beneficiaries of the Joint Programme have received a mandate by their national programme owner to participate in the EURAD implementation phase (the mandate shall confirm that organisations are responsible for managing/implementing a RWM programme and/or managing/ implementing a RD&D programme needed for implementation). The Joint Programme assumes no responsibilities for maintenance or impact of the National Programme. The Joint Programme is complementary to Member States National Programme, and the interactions between the two are managed via the national mandate. This includes the preservation of the independence and role of Beneficiaries in the national-decision making process.

According to Article 6 of the 2011/70/EURATOM directive, Member States shall ensure that the competent regulatory authority is functionally separated from any other body or organisation concerned with the management of spent fuel and radioactive waste, in order to ensure effective independence from undue influence on its regulatory function. This requirement has several implications for the expertise function which is aimed at providing the technical and scientific basis for supporting the decision made by the regulatory function. Arrangements must therefore be made by the Members States National Programme to maintain the independence role of potentially different Joint Programme participants. Regarding the EURAD, the use and interpretation of results, (produced by the Joint Programme) in the context of the national geological disposal programme is the respective responsibility of the WMOs and TSOs.

6.2. Evaluation

To assess the Joint Programme outputs, early affects and long-term impacts, monitoring and evaluation criteria will be constructed that will serve as the basis for the development of a set of key performance indicators. This criteria will be built in close consultation and collaboration with the Joint Programme participants and will align with objectives within the scientific Themes, and prioritised RD&D, strategic studies and knowledge management activities presented in the Strategic Research Agenda.

By mandating organisations to participate, Member States demonstrate that the European Joint Programme has an EU-added value beyond their National Programme. As the Joint Programme is not working in direct support for implementation of RWM operations or geological disposal, it is the responsibility of the National Programmes to evaluate outputs and results with respect to their own needs (towards implementation). Quality and scientific excellence can however be harmonised, and

will always represent a primary criterion for evaluation of EURAD proposals and results, and assumes over-riding importance in the first 5-year implementation plan.

The scope of criteria for evaluating the overall Joint Programme (and for individual Work Packages) will include:

- The Joint Programme/Work Package must articulate the overall research vision. To enhance the potential of achieving it, a world-class team of complementary expertise should have been brought together.
- The Joint Programme/Work Package should be ambitious, creative, innovative, and address key research challenges. It should also be sustainable beyond the lifetime of the programme itself.
- A strong scientific case for support must be demonstrated by the Joint Programme/Work Package with the proposed research set into the context of the current state of knowledge and other work under way in the field.
- The Joint Programme/Work Package expected outputs should result in a significant step change, with major impact on the research area beyond the immediate project team, and appreciably raise the international profile of European radioactive waste RD&D.
- The Joint Programme/Work Package should clearly demonstrate the methods intended to be used to attain the stated objectives and describe clearly how appropriate they are for the planned activity and their scientific or technical feasibility. Where there is not a detailed methodological plan for the whole period of the implementation plan, the proponents should explain how the research in the latter years will be identified.
- The Joint Programme/Work Package should identify the most significant challenges to achieving the stated objectives and explain how these will be addressed.
- The Joint Programme/Work Package must show clearly how meaningful, independent peer review will be integrated on a timely basis within the overall implementation plan.

Annex 1 – EURAD Terms of Reference

Terms of Reference – General Assembly of the European Joint Programme on Radioactive Waste Management (EURAD)

COMPOSITION

It is composed of one representative of each organisation having received a mandate by their national programme owner to participate as Beneficiary in the JP implementation phase (the mandate shall confirm that organisations are responsible for managing/implementing a RWM programme and/or managing/ implementing a RD&D programme needed for implementation).

Beneficiaries fall into one of the three following categories: Waste Management Organisations (WMOs), Technical Support Organisations (TSOs) and Research Entities (REs). Each category has its own college within the General Assembly:

- WMOs college;
- TSOs college; and
- REs college.

ROLE

The General Assembly is the ultimate decision-making body of the Joint Programme consortium. It is responsible for agreeing the strategy of the EURAD in line with the content of the SRA/Roadmap and the Euratom Work Programme. The General Assembly shall be assisted by the Bureau and by the Programme Management Office. Proposals by the Bureau and by the Programme Management Office shall be considered and decided upon by the General Assembly. The General Assembly shall be free to act on its own initiative to formulate proposals and take decisions, following preview with the Bureau and/or Programme Management Office.

The General Assembly responsibilities are to:

Vision, Strategic Research Agenda (SRA), and Roadmap

- Approve Vision, SRA, and Roadmap
- Decide on possible update of the Vision/ SRA / Roadmap

Governance

- Approve the EURAD Governance (and any update)
- Approve deployment/implementation mechanisms (and any update)
- Appoint the Bureau Members

Deployment Plan

- Approve the deployment of activities (Approve RD&D, Strategic Studies, Knowledge Management)

5-year Implementation phases (ruled by Grant Agreement and Consortium Agreement)

- Approve management procedures (incl. Quality Management System, budgeting and payment procedures, reporting procedures, internal communication procedures)
- Approve annual dissemination plan and publication procedure
- Approve annual reports to EC

- Identify a breach by a Party of its obligations under the Consortium Agreement or the Grant Agreement
- Declare a Party to be a defaulting party
- Approve modification of the Consortium Agreement/Grant Agreement
- Approve entry of a new party/withdrawal of a party
- Proposal to the Commission for a change of the Coordinator

DECISION-MAKING PROCESS

Decisions in the General Assembly shall preferably be taken by consensus view*, without a formal voting system. In the event that a decision cannot be taken by consensus view in a first instance, the following stepwise approach applies:

- **For decisions concerning *Vision*, *Roadmap*, *SRA*, *Governance* and *Deployment Plan***

Each college of the General Assembly (WMO college, TSO college and RE college) expresses its position regarding the decision to be taken with its own internal rules (process should be described). The decision is taken when the three colleges' positions take the same decision.

If after the colleges' position the decision is not taken, the General Assembly mandates the Bureau to work on a new proposal that shall take into account comments made by General Assembly.

- **For decisions concerning implementation phases:**

Each Beneficiary shall have one vote. Decisions shall be taken by a majority of two-thirds of the votes cast.

**No formal quorum has been established by the EURAD.*

MEETINGS

The General Assembly shall meet at least twice a year. Extraordinary meetings for urgent issues may be convened at any time upon written request of at least 10% of its members.

The members of the Bureau and the PMO will also participate in the General Assembly meetings. It is anticipated that the CSO observer of the Bureau and the WP Leaders shall be invited as observers, however the General Assembly reserves the right to call closed meetings, if required.

Terms of Reference – Bureau of the General Assembly of the European Joint Programme on Radioactive Waste Management (EURAD)

COMPOSITION

The Bureau shall be composed of three representatives elected by each General Assembly college together with one CSO representative as observer.

- The WMOs College elects its three Bureau representatives (including one representative from a country with early stage/ small RWM programme).
- The TSOs College elects its three Bureau representatives (including one representative from a country with early stage/small RWM programme).

- The REs College elects its three Bureau representatives (including one representative from a country with early stage/small RWM programme).
- The CSO observer (elected by the CSOs).

The composition of the Bureau shall be regularly reviewed for suitability of roles, responsibilities and membership (at least by mid-term of the first 5-year implementation). This shall be done through consultation with each of the Colleges and any changes approved by the General Assembly.

ROLE

The Bureau is an accompanying body to the General Assembly for what concerns high-level strategic issues as laid down by the Joint Programme Vision, SRA and Roadmap. It shall prepare any decisions to be taken by the General Assembly that concerns any update of the Vision, SRA and Roadmap as well as proposals for the Deployment Plan (this includes the second wave of RD&D and Strategic Studies, as well as the Annual Programme of Knowledge Management).

The Bureau members shall represent the interests of their respective community, not the interest of their own organisation.

The Bureau members act in close interactions with the Programme Management Office.

MEETINGS

The Bureau shall meet regularly, at least twice per year (in addition to its participation in the General Assembly meeting). The Project Management Office shall participate in the Bureau meetings. Additional experts and Civil Society representatives may also participate in the Bureau meeting as needed.

Terms of Reference – Programme Management Office (PMO) and Coordinator of the European Joint Programme on Radioactive Waste Management (EURAD)

COMPOSITION

Programme Management Office is composed of 2 to 3 officers.

The PMO is housed in the premises of the Coordinator, to which staff from the Beneficiaries can be seconded on a full-time basis.

ROLE

The Programme Management Office shall be responsible for the proper execution and implementation of the work plan approved by the General Assembly. The Programme Management Office is in charge of scientific and technical coordination of the overall programme (RD&D, Strategic Studies, Knowledge Management), as well as the day-to-day management (budget follow-up, reporting exercises…) and communication/dissemination activities.

The Programme Management Office, together with the Bureau, makes proposal to be decided upon by General Assembly. The Programme Management Office interacts with the EC and key stakeholders: national programmes, international organisations/programmes, External Advisory Board, etc.

MEETINGS

The PMO shall organise regular meetings (at least twice a year) gathering all the Work Package Leaders to facilitate good interactions between themselves and to maintain coordination of all their activities, to ensure joint programming.

Terms of Reference: Work Package Boards of the European Joint Programme on Radioactive Waste Management (EURAD)

COMPOSITION

For each Work Package (WP) a WP Board is set-up. It comprises the Work Package Leader and the task leaders.

ROLE

The WP Board is in charge of the scientific and technical coordination of the WP. The WP Board ensures that the WP is progressing according to the agreed specifications, milestones and planning. The WP Board is also responsible to report work progress, any WP deliverables and eventual modifications of the WP work plan to the Programme Management Office.

MEETINGS

At least 2 meeting per year, at least one shall be in coordination with all EURAD WP Boards together with the PMO to encourage interactions, integration and cross-harmonisation.

Terms of Reference: External Advisory Board (EAB) of the European Joint Programme on Radioactive Waste Management (EURAD)

ROLE

The external advisory board advises the General Assembly on strategic and implementation issues related to the EURAD Work Plan and its coherence with respect to the Strategic Research Agenda and Vision.

COMPOSITION

- Scientific and technical experts at international level ;
- Civil Society Representatives
- EC representative
- IAEA representative
- Other international organisations

The EAB will be invited to one annual GA meetings and shall provide external advices and recommendations for the implementation of the EURAD.

Annex 2 – Development of the EURAD Strategic Research Agenda

The Strategic Research Agenda of the Joint Programme has been developed in a stage-wise manner, Step 1 - taking over entirely the scope developed within the EC JOPRAD Project (See Annex 4, JOPRAD Programme Document D4.2), and Step 2 – enhancing with a small number of additional needs identified by ongoing EC projects and approved for inclusion between the key contributors of the JP.

Step 1 – Taking over the EC JOPRAD Project Scope: The Joint Programme has reorganised the JOPRAD scientific and technical scope into 7 Scientific Themes (as described fully in Chapter 3, the JOINT PROGRAMME SRA). Each activity has retained (i) the activity title (with some minor editing to make the research objectives more SMART - Specific, Measurable, Attainable, Relevant and Timely); (ii) the indicator of High, Medium or Low for the 'level of common interest' between the WMOs, TSOs, and REs groups represented within JOPRAD, and further commented on by an open European consultation (managed by the JOPRAD project) during the summer of 2017; and (iii) an indication of whether scope to address the identified activity would benefit from a Knowledge Management component.

*The EC JOPRAD project methodology for identifying the scientific and technical basis of the JOPRAD SRA was carried out in 5 steps:

1. **Compiling Activities for Inclusion**: Drafting a first compilation of combined activities suggested as suitable for inclusion within a potential future Joint Programme. A key part of this step was to organise and coalesce suggested activities (identified from WMO, TSO and RE-specific SRAs) into a suitable structure, considering the different types of activities suggested and the adoption of a common terminology and appropriate scope definition for a potential future Joint Programme;
2. **Surveying Representative Joint Programme Participant Views**: Eliciting JOPRAD participants' opinions on their preferences and motivations for prioritising activities. This was completed by issuing a comprehensive questionnaire of suggested activities, allowing JOPRAD participants to comment and express views on activities suggested by all the represented groups for the first time;
3. **Identifying Priorities and Activities of High Common Interest**: Analysing the questionnaire responses to identify the themes with high common interest, and the adoption of screening criteria used to prioritise what should be included in the Joint Programme. This step included development of a methodology to cross-check that all prioritised activities met with the established boundary conditions for the Joint Programme;
4. **1st Draft SRA**: Drafting a first compilation of the Joint Programme scientific and technical scope with a clear description of prioritised RD&D activities agreed and supported by all JOPRAD participants;
5. **SRA Consultation and Finalisation**: Consultation of the draft scientific and technical scope within the broader European radioactive waste management community. Obtaining feedback and end-user input to facilitate updating of the final Programme Document.

The JOPRAD WP4 Programme Document (see chapter 6) also includes specific "socio-political confidence building themes" addressing the complexity of RWM. Three main areas of scope were identified, which could be integrated within future R&D and strategic studies WPs, where appropriate. Integration in this way would ensure the JP does not give rise to self-standing social and political research activities, separate from the technical aspects of RWM.

EURAD Themes	JOPRAD RD&D Sub-topics and New Scope (*greyed boxes show new scope since JOPRAD and origin / title changes made in the JP, shown in italics and brackets*)	Level of Common Interest for RD&D	Identified Knowledge Management Activity
Theme 1: Managing Implementation and oversight of a Radioactive Waste Management Programme	3.15 EU Research Infrastructure	High	✓
	Establishment and implementation of a RD&D programme (Originates from guidance needs identified by the IGD-TP PLANDIS Guide)	High	✓
	3.14 Information Management (NEA RepMet)	Medium	✓
	3.16 EU DGR Curricular (*JP title: Training and competence maintenance of skills and expertise to support safe radioactive waste management including disposal*)	Low	✓
	3.11 Pre-licensing Management	Low	✓
Theme 2: Radioactive waste characterisation, processing and storage (Pre-disposal activities), and source term understanding for disposal	1.1.1 Inventory Uncertainty *(JP title: Identifying good practice in the management of inventory data and uncertainty treatment*)	High	✓
	1.1.3 Non-mature and Problematic Waste Conditioning (*JP title: Developing novel conditioning technologies for non-mature and problematic waste*)	High	✓
	1.1.4 Radionuclide Release from Wasteforms other than Spent Fuel (*JP title: Improved understanding of radionuclide release from existing and future wasteforms other than Spent Fuel*)	High	✓
	1.1.2 Waste Characterisation Techniques (*JP title: Developing reliable and affordable technologies for the radiological characterization and segregation of historical preconditioned radioactive waste*)	High	
	1.2.2 Impacts of Extended Storage on Waste Packages (*JP title: Improved understanding of the impacts of extended storage on waste package performance*)	High	✓
	1.4.2 Gas Generation Processes (*JP title: Improved understanding of the generation and release of radioactive trace gases and bulk gases from wasteforms and waste packages*)	High	
	2.4.5 Interim Storage Facility Safety (*JP title: Operational lifespan of interim storage facilities*)	High	
	Waste Management Routes across Europe considering different waste types and their specified endpoints (Originates from networking needs identified by ENEF NAPRO Guide)	High	✓
	1.1.5 Geopolymers (*JP title: Demonstration of geopolymer performance in representative disposal conditions*)	Medium	
	1.1.7 Chemotoxic Species (*JP title: Improved understanding of the nature and quantities of the likely chemotoxic component of common wastes*)	Medium	
	1.1.8 Novel Radioactive Waste Treatment Techniques (*JP title: Optimisation of radioactive waste treatment techniques where there is potential for volume/hazard reduction and potential cost savings*)	Medium	

	1.1.9 Spent- Fuel Evolution (*JP title: Improved understanding of the behaviour of packaged Spent Fuel for a range of hypothetical fire and impact scenarios during operations and transport, and consolidation of existing understanding of post-closure Spent Fuel release processes*)	Medium	✓
	3.5 Inventory Collation & Forecasting	Medium	✓
	2.1.6 Waste Acceptance Criteria	Medium	✓
	1.1.10 Spent Fuel Fissile Content (*JP title: Quantification of fissile content of spent fuel*)	Low	
	3.7 Link to Waste Producers/ Fuel Manufacturers (*JP title: Strengthened links between Implementers and Waste Producers*)	Low	✓
	3.6 Evolution of Waste Inventory (*JP title: Methodologies applied to define radionuclide inventories*)	Low	✓
	3.10 Disused Sealed Radioactive Sources (*Understanding of the potential for long-term storage as a management option for disused sealed radioactive sources*)	Low	✓
	1.2.4 Reworking of Damaged and Aged Waste Packages (*JP title: Management of damaged waste packages and the criteria and methods for reprocessing aged waste*)	Low	✓
	1.1.6 Fourth generation (Gen (IV)) wastes	Low	
Theme 3: Engineered barrier system properties, function and long-term performance	1.2.1 Waste Package Interfaces (*JP title: Improved understanding of the interactions occurring at interfaces between waste packages and different barriers in the disposal facility*)	High	
	1.3.1 Bentonite and other Clay Based Components (*JP title: Characterised bentonite / clay-based material evolution under specific conditions to provide data on hydro-mechanical, thermal and chemical behaviour*)	High	
	1.3.2 Microbial Influence on Gas Generation (*JP title: Improved chemical and microbial data to better quantity gas generation and the consequences of microbial processes*)	High	
	1.3.3 Cementitious Component Behaviour (*JP title: Improved quantification and understanding of cement-based material evolution to improve long-term modelling and assessments*)	High	
	1.3.5 Metallic & Cementitious Chemical Perturbations (*JP title: Improved understanding of the impacts of different metallic and cementitious component phenomena on near-field evolution via improved models*)	High	
	1.4.4 Gas Reactivity in the EBS (*JP title: Improved understanding of gas reactivity in the EBS*)	High	
	2.2.2 Performance of Plugs and Seals (*JP title: Improved understanding of the performance of plugs and seals*)	High	
	1.2.3 Alternative HLW/Spent Fuel Container Material Development (*JP title: Developing alternative HLW and Spent Fuel container material options and improved demonstration of their long-term performance*)	Medium	

	1.3.4 Low pH Cements (*JP title: Improved understanding of low pH cements*)	Medium	
	1.3.7 HLW/ILW Near-field Evolution (*JP title: 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*)	Medium	
	1.3.6 Salt Backfill (*JP title: Improved understanding of a salt backfill*)	Low	
	1.3.8 Co-Disposal Interactions (JP title: Identify co-disposal interactions of importance to long-term safety)	Low	✓
Theme 4: Geoscience to understand rock properties, radionuclide transport and long-term geological evolution	1.4.1 Gas Migration through the Excavated disturbed Zone/EBS and Far-Field (*JP title: To increase understanding of gas migration in different host rocks*)	High	
	1.4.4 Gas Reactivity in the Geosphere (*JP title: Improved understanding of gas reactivity in different host rocks*)	High	
	1.5.2 Sorption, Site Competition, Speciation and Transport (*JP title: Improved representation of sorption mechanisms and coupled chemistry / transport processes for various media*)	High	
	1.5.5 Effects of Microbial Perturbations on Radionuclide Migration (*JP title: Improved understanding of bounding conditions for the effects of microbial perturbations on radionuclide migration to support performance assessments*)	High	
	3.2 Site Evolution Models (*JP title: Development of site evolution models, and how to manage data as it is obtained during the site characterisation phase*)	High	
	1.4.3 Gas Transients (*JP title: Develop and implement two-phase flow numerical codes to increase gas transient representation at the disposal scale*)	Medium	
	1.5.3 Incorporation of Radionuclides in Solid Phases (*JP title: Quantification of long-term entrapment of key radionuclides in solid phases to inform reactive transport models*)	Medium	
	1.5.4 Transport of Strongly Sorbing Radionuclides (*JP title: Improved understanding of the transport of strongly sorbing radionuclides*)	Medium	
	1.5.6 Organic-Radionuclide Migration (*JP title: Improved understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration*)	Medium	
	1.5.7 Temperature Influence on Radionuclide Migration (*JP title: Improved understanding of the influence of temperature on radionuclide migration and representation of effects in geochemical models*)	Medium	
	1.5.8 Colloid Influence on Radionuclide Migration (*JP title: Improved understanding of the role of colloids and their influence on radionuclide migration*)	Medium	

	1.5.9 Redox Influence on Radionuclide Migration (*JP title : Improved understanding of the influence of redox on radionuclide migration)*	Medium	
	1.5.10 Ligand-Influenced Transport Modelling (*JP title: Improved understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration*)	Medium	
	1.5.11 Transport of Volatile Radionuclides (*JP title: Developing a geochemical model for volatile radionuclides*)	Medium	
	2.2.6 Biosphere Models (*JP title: Enhanced treatment of climate change, non-human biota, land-use and parameter derivation in biosphere models*)	Medium	
	1.6.3 Groundwater Evolution (*JP title: Developing models of groundwater evolution*)	Medium	
	1.6.1 Fracture Filling (*JP title: Improved understanding of the processes of fracture filling*)	Low	
	1.6.4 Rock Matrix Diffusion (*JP title: Impact of rock matrix diffusion on travel time through the geosphere*)	Low	
Theme 5: Geological disposal facility design and the practicalities of its safe management:	2.5.1 Operational Monitoring Strategies (*JP title: Developing monitoring strategies appropriate to the operational phase (including facility construction and work acceptance) of geological disposal facilities that will not adversely affect the performance of the disposal system*)	High	
	2.5.3 Monitoring Technologies (*JP title: Developing innovative monitoring technologies*)	High	
	2.5.2 Monitoring Strategies for Closure and Post-closure (*JP title: Developing appropriate monitoring technologies for closure and a period of post-closure institutional control in links with relevant parameters for safety*)	Medium	
	2.5.7 Industrialization (*JP title: Optimization of backfilling and other major implementation processes, including waste emplacement, retrieval and sealing technologies*)	Medium	
	2.5.8 Engineering Asset Management(*JP title: Developing cost-effective asset management strategies for use in the design*)	Medium	✓
	2.5.4 Retrievability (*JP title: Improved understanding of waste package durability and disposal facility infrastructure with respect to retrievability*)	Low	
	2.5.5 Concept and Design Adaptation (*JP title: Assessment of the technical feasibility and lifecycle adaptation of a geological disposal concept for a specific site and specific nuclear waste type*)	Low	
	2.5.6 Mock-up Experiments (*JP title: Verify robustness of disposal system designs using large scale mock ups*)	Low	
	2.4.4 Accident Mgt. and Emergency Preparedness	Low	✓
	2.4.2 Flooding Risk Assessment (*JP title: Developing operational hazard assessment methodologies (inc. flooding risk*))	Low	
	3.8 Concept Adaptation and Optimisation (*JP title: Assessment of the technical feasibility and lifecycle*	Low	✓

	adaptation of a geological disposal concept for a specific site and specific nuclear waste type)		
	3.12 Co-disposal Interactions (*JP title: Managing co-disposal*)	Low	✓
	3.13 Radiation Protection Optimisation Principle	Low	✓
	3.17 Reversibility	Low	✓
Theme 6: Siting and licensing:	1.6.5 Site Descriptive Models (*JP title: Maintaining and developing understanding of tools and techniques for developing site descriptive models*)	High	✓
	3.1 Site Uncertainty Treatment *(JP title: Methodologies for site uncertainty treatment)*	High	✓
	1.6.2 Geological Uncertainties (*JP title: Developing state-of-the-art on the methods of uncertainty management associated with site characteristics*)	Medium	
	3.3 Site Selection Process	Medium	✓
	3.4 Technical and Socio-political Siting Criteria	Low	✓
Theme 7: Performance assessment, safety case development, and safety analyses:	2.2.1 THMC Evolution (*JP title: Improved understanding and models for the impact of THMC on the behaviour of the host rock and the buffer materials*)	High	
	2.2.4 Upscaling THMC Models (*JP title: Improved understanding of the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space*)	High	
	2.3.4 Multi-scale Reactive Transport Models (*JP title: Improved multi-scale reactive transport models*)	High	
	1.5.1 Chemical Thermodynamics (*JP title: Further develop transparent and quality assured thermodynamic databases for use in performance assessments and supporting models*)	High	
	2.1.1 Pre-closure disturbances (*JP title: Improved understanding of the influence of pre-closure disturbances on long-term safety*)	Medium	✓
	2.1.2 Assessment Methodologies	Medium	✓
	2.1.3 Uncertainty Treatment (*JP title: Further refinement of methods to make sensitivity and uncertainty analyses*)	Medium	✓
	2.2.5 Natural Analogues (JP title:)	Medium	✓
	2.3.1 Performance Assessment Tools (*JP title: Improved performance assessment tools*)	Medium	
	2.3.3 Long-range Transport Models (*JP title: Improve geosphere transport models)*	Medium	
	2.3.5 Upscaling in Support of Performance Assessment (*JP title: Improved understanding the role of physical/chemical processes at different scales and linking bottom-up and top-down approaches in performance assessments*)	Medium	
	2.3.6 Heterogeneity (*JP title: Improved treatment of heterogeneity*)	Medium	
	2.3.7 Improved Computing	Medium	
	3.9 Safety Case Guidelines, Management & Review	Medium	✓
	2.1.4 Dose Thresholds	Low	

	2.1.5 Managing Deviations (*JP title: Improved understanding for the impact of deviations in planned implementation scenarios on the performance assessment outputs of the disposal facility*)	Low	
	2.2.3 Oxidative Transients (*JP title: Improved understanding of the spatial extent and evolution with time of oxidative transients, as well as the possible impact on safety functions*)	Low	
	2.3.2 Open-source Performance Assessment Code	Low	
	2.4.1 Fire and Explosion Assessment (*JP title: Improve fire and impact assessment*)	Low	
	2.4.3 Improve Understanding of the Impacts of Operational Safety	Low	

Further details of the JOPRAD methodology for identifying the scientific and technical basis of the Joint Programme is presented in Section 4 of JOPRAD deliverable D4.2 Programme Document.

Step 2 – The Joint Programme has been developed in parallel with the completion/near completion of EC Horizon 2020 projects (See Annex 4, Horizon 2020). Several new needs have therefore been identified as a result of recent RD&D results, and / or that are now considered of higher common interest by the contributors and participants of the Joint Programme. These needs have been approved for inclusion in the SRA through various meetings between representatives of WMOs, TSOs and RE's to ensure the needs meet with the same boundary conditions used by JOPRAD, and are suitable for Joint Programming.

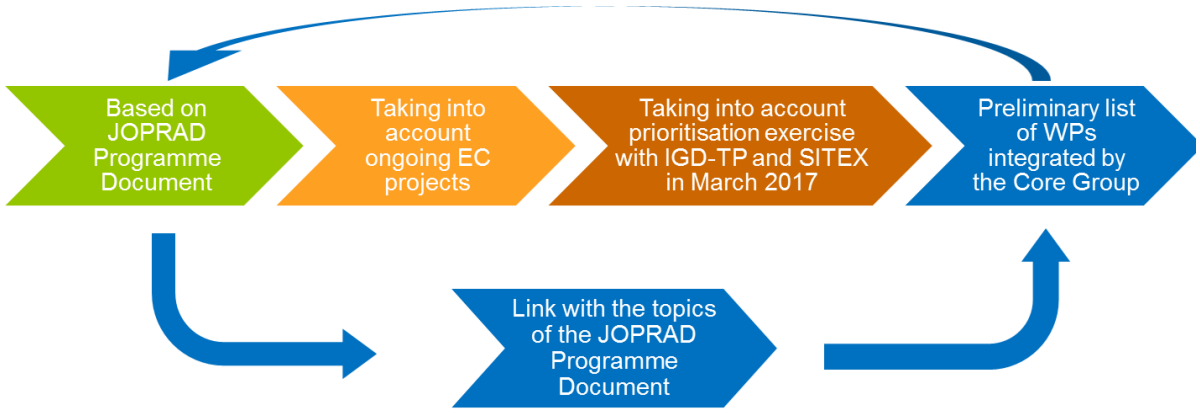
The table below maps the JOPRAD sub-topics, and newly identified scope to the 7 Scientific Themes of the EURAD SRA.

Table: EC JOPRAD scope and newly identified scope mapped to Themes of the EURAD SRA

Annex 3 – Development of the EURAD Deployment Plan 2019-2024

This Annex describes how the list of RD&D/Strategic Studies WPs for the launch at the start of the Joint programme were established, i.e. for the first phase, referred to as EURAD 1 ("first wave"). A similar process shall be used for the launch of the "second wave".

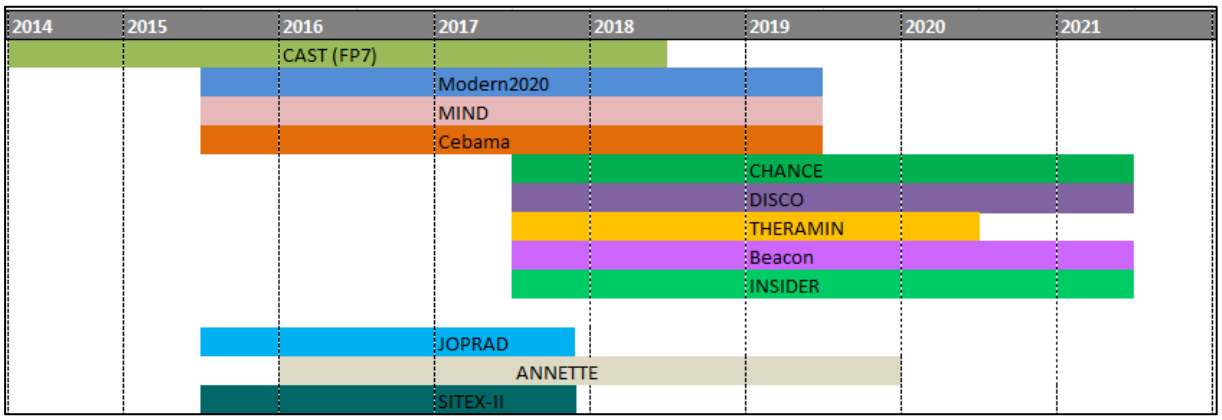
The preliminary list of collaborative RD&D, strategic studies and knowledge management work packages (WPs) have been established based on the following process:



In February 2017, the core group specified the following boundary conditions that have to be taken into account prior suggesting RD&D and networking WPs:

- Each WP has to be in line with the vision and the JOPRAD Programme Document, in particular with respect to the results of the questionnaire. Specifically, each WP has to address mainly topics of high or medium level of common interest from the JOPRAD Programme Document.
- The suggested WPs have to be of common interest by the different categories of actors: REs, TSOs and WMOs.
- The suggested WPs should avoid (i) duplication of existing international activities (e.g. from NEA or IAEA) and (ii) re-doing what has been done in the past (at national or European level).
- The WPs have to address topics which are not currently addressed by ongoing EC projects. The ongoing EC projects are given on the following figure. The different topics addressed in ongoing EC projects are the following: monitoring (Modern2020), microorganisms (MIND), concrete alteration (Cebama), non-destructive assay methods (CHANCE), waste thermal treatment (THERAMIN), bentonite mechanical evolution (Beacon) and characterization of dismantling waste (INSIDER). The aim of this is to wait for feedback from these ongoing projects before launching any follow up WP within EURAD 1.

Figure 8 – Illustration of recently completed or existing EC Funded Horizon2020 Projects in Radioactive Waste Management



The selection process followed a top-bottom approach. In March 2017, a first list of WPs was prioritized by the Executive Group (EG) of IGD-TP for the WMOs, and SITEX for the TSOs. Following this, the Core Group established a list of potential WPs and issued a call for interest.

1. WMOs Proposal

The main ideas that guided the selection of the EG of the IGD-TP were first to find a good balance between mature and emerging projects to be launched at start of EURAD 1, and then to keep it simple for the first round.

As a result, a set of four topics was first issued by RWM and SKB, and three subsequent topics were then added by ONDRAF/NIRAS and Andra. This list included three matures projects and four new and challenging topics. The three mature projects are listed hereafter:

- Cement-Organics-Radionuclides-Interactions: this topic address both surface disposal and deep geological disposal. It needed to be reworked and significantly improved;

- Safety of Extended dry storage of nuclear spent fuel: this project may not be relevant to all EG members. It needed to be reworked and significantly improved;
- High temperature clay interactions: the topic is a first step toward optimization of the architecture of the deep geological disposal. The idea was to continue the work begun at WG3 from EF7.

The four emerging topics fall into two different categories:

- The topic dedicated to the assessment of chemical evolution of ILW and HLW disposal seems adequate in the context of an Joint Programme towards implementation of actual repositories. It corresponds to an integration challenge that all WMO's are facing or will be facing at some point (managing the complexity of the phenomenological evolution of these subsystems, managing uncertainties…);
- The other three topics fit in the area of long-term scientific endeavour to strengthen safety cases, reduce conservatism and maintain skills:
    - Fundamental understanding of radionuclide mobility;
    - Mechanistic understanding of gas migration; and
    - Numerical methods and tools applied to performance assessment.

2. TSOs proposal

The five following topics have been suggested:

- Metallic component behaviour along the stages of storage and disposal programmes;
- Gas migration;
- Radionuclide migration through disturbed engineered barrier systems and host rocks,
- Conditions for closure; and
- Management of uncertainties.

Based on the proposals from WMOs and TSOs, the Core Group established the following list of RD&D/Strategic Studies WPs:

- (RD&D) Modelling of process couplings and numerical tools applied to PA;
- (RD&D) Assessment of chemical evolution of ILW and HLW disposal cell;
- (RD&D) Mechanistic understanding of gas migration (mainly in clay-based materials);
- (RD&D) Influence of temperature on clay-based material behaviour;
- (RD&D) Cement-Organics-Radionuclide-Interactions;
- (RD&D) Fundamental understanding of radionuclide mobility;
- (RD&D) Spent Fuel characterization and evolution until disposal;
- (Strategic Studies) Understanding of uncertainty, risk and safety; and
- (Strategic Studies) Waste management routes in Europe from cradle to grave*.

* This Strategic Studies emerged in April 2017 following the JOPRAD Programme document workshop in London in order to meet the expectations from small / early stage programmes.

This list of potential WPs was then checked and agreed by REs (this work was coordinated by CNRS).

Based on this list of potential WPs, a Call for Interest was issued in April 2017 to collect interest/ potential contributions by the different organisations. All WPs received a high-level of interest. Nine working groups have been established in June 2017 to officially start the proposals development.

Annex 4 – Supporting Documents & References

1. Aarhus Convention: The United Nations Economic Commission for Europe (UNECE) Convention on access to information, public participation in decision-making and access to justice in environmental matters, Aarhus, Denmark, 25 June 1998.
2. EC Progress Report on Progress of Implementation of Council Directive 2011/70/EURATOM: Report from the Commission to the Council and 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, Brussels, 15.5.2017, COM(2017) 236 final.
3. ENEF NAPRO Guide: Guidelines for the Establishment and Notification of National Programmes developed by the European Nuclear Energy Forum (ENEF) Work Group, 2013.
4. EU Horizon 2020 Research and Innovation Programme: Research at European level funded through Euratom Research and Training Programmes. Fission research actions cover: safety of nuclear systems; safe long-term management of radioactive waste; development and sustainability of nuclear expertise and excellence in the EU; risks of low and protracted exposure to ionising radiation, including in medical applications; and research infrastructures and education and training.
5. IAEA - Developing Multi-national Radioactive Waste Repositories - Viability of Sharing Facilities for the Disposal of Spent Fuel and Nuclear Waste, IAEA-TECDOC-1658, 2011.
6. IAEA Joint Convention: Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna, Austria, 1997.
7. IAEA Safety Standards Series SSG-23: The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, No. SSG-23, ISBN:978-92-0-128310-8, IAEA, 2012.
8. IAEA Scientific and Technical Basis for Near Surface Disposal of Low and Intermediate Level Waste, IAEA Technical Report Series #412, STI/DOC/010/412, ISBN 92-0-118702-5, IAEA 2002.
9. IAEA Scientific and Technical Basis for the Geological Disposal of Radioactive Waste: IAEA Technical Report Series #413, STI/DOC/010/413, ISBN 92-0-100103-7, publ. IAEA 2003.
10. IAEA Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste: IAEA-TECDOC-1755, ISBN:978-92-0-109914-3, IAEA, 2014.
11. IGD-TP - Implementing Geological Disposal Technology Platform: The collaborative body which coordinates RD&D needs of the implementers of geological disposal at the European level, established in 2009. The IGD-TP publish and maintain their own strategic research agenda.
12. JOPRAD - Towards a Joint Programming on Radioactive Waste Disposal: EC project that completed initial preparatory work for the potential setting up of Joint Programme on radioactive waste management and disposal. JOPRAD identified the scientific and technical basis of a future joint Programme in the D4.4 Programme Document together with considerations for a financing and governance scheme, published in the D3.2 Conditions for Implementing a Joint Programme.
13. NEA - Stepwise Implementation: Stepwise Approach to Decision Making for Long-term Radioactive Waste Management, Experience, Issues and Guiding Principles, NEA No. 4429, Nuclear Energy Agency, 2004.
14. NEA – Underground Testing: Going Underground for Testing, Characterisation and Demonstration, NEA Radioactive Waste Management Committee Report NEA/RWM(2001)6/REV, publ. OECD Nuclear Energy Agency 2001.

15. NUGENIA - Nuclear Generation II & III Association: Association of more than 100 members worldwide to advance the research and development of nuclear fission technologies, in particular for Generation II and III nuclear plants.
16. Official Journal of the European Union Nuclear Safety Directive: OJEU (2011), The Council Directive 2009/71/EURATOM, establishing a Community framework for the nuclear safety of nuclear installations, Official Journal of the European Union, f 25 June 2009.
17. Official Journal of the European Union Waste Directive: OJEU (2011), The Council Directive 2011/70/EURATOM, establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, Official Journal of the European Union, 2 August 2011.
18. PLANDIS Guide: RD&D Planning Towards Geological Disposal of Radioactive Waste Deliverable D-No:2.3, Guidance for less-advanced programmes, 2015.
19. SITEX - Sustainable Network for Independent Technical Expertise of Radioactive Waste: A network of organisations carrying out activities aimed at providing the technical and scientific basis for notably supporting the decisions made by the national regulatory body established in 2012. The SITEX network issued their first strategic research agenda in 2016.
20. Underground Research Facilities: Underground Research Facilities and Rock Laboratories for the Development of Geological Disposal Concepts and Repository Systems by I. Blechschmidt and S. Vomvoris, Chapter 4 in Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste, ISBN 978-1-84569-542-2, publ. Woodhead Publishing 2010.
21. WENRA - Western European Nuclear Regulators Association: WENRA is a network of chief nuclear safety regulators in Europe exchanging experience and discussing significant safety issues. It aims to develop a common approach to nuclear safety and to provide an independent capability to examine nuclear safety in applicant countries.

END OF DOCUMENT