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Work Package 4

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Abstract

This Programme Document sets out the scientific and technical basis of a future Joint Programme on Radioactive Waste Management and Disposal. In its current form, it is a deliverable of the EC 'Towards a Joint Programme on Radioactive Waste Disposal - JOPRAD' project and represents the views of JOPRAD participants on research, development and demonstration (RD&D) priorities considered as suitable for Joint Programming. The JOPRAD Project was established in 2015 with the objective of completing initial preparatory work for the potential setting up of Joint Programming on radioactive waste disposal, the scope of which has since broadened to cover radioactive waste management and disposal so that it also captures related pre-disposal activities.

To obtain the support of the wider European Radioactive Waste Community, the contents herein were disseminated and the draft document made available for open consultation during the period March – April 2017. Finalisation and issue to the European Commission is expected by the end of December 2017. After this time, it is anticipated that this Programme Document (in its final form of a Strategic Research Agenda) will be taken over in-part or wholly by those responding to the European Commission EURATOM H2020 Call (WP2018) in the form of a Joint Programme Proposal.

JOPRAD participants include a sub-set of European Radioactive Waste Management Organisations, Regulatory Technical Support Organisations, Research Entities and Civil Society experts, representative of the Actor Groups mandated to conduct or manage RD&D in relation to Radioactive Waste Management within Member States of the European Union. To identify the RD&D priorities of common interest between the JOPRAD participants and Actor Groups, an open and transparent process has been used and the reasons for selection/rejection of potential activities fully explained.

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Glossary

ALARP	As Low As Reasonably Practicable.
BEACON	EC Project – Bentonite Mechanical Evolution.
BELBAR	EC Project – Long term performance of the engineered barrier and radionuclide transport.
BENIPA	EC Project - Bentonite Barriers in Integrated Performance Assessment.
BAT	Best Available Technology.
CARBOWASTE	EC Project - Treatment and Disposal of Irradiated Graphite and Other Carbonaceous Waste.
CAST	EC Project - CArbon-14 Source Term.
CatClay	EC Project - Processes of Cation Migration in Clay rocks.
CHANCE	EC Project – Characterization of conditioned nuclear waste.
DISCO	EC Project – Disruptive Competition Project.
DOPAS	EC Project – Demonstration Of Plugs And Seals.
DSRS	Disused Sealed Radioactive Sources.
EBS	Engineered Barrier System.
EC	European Commission.
EC DG-RTD	European Commission Directorate General for Research and Innovation.
ECVET	European Credit system for Vocational Education and Training.
EDZ	Excavation Disturbed Zone.
EJP	European Joint Programme.
EURATOM	European Atomic Energy Community.
FEBEX	EC Project - Full-Scale Engineering Barrier Experiment in Crystalline Host Rock.
FIRST-NUCLIDES	EC Project – Fast/Instant Release of Safety Relevant Radionuclides from Spent Nuclear Fuel.
FORGE	EC Project - Fate Of Repository Gases.
GDF	Geological Disposal Facility.
Gen IV	Generation IV reactors.
H2020	Horizon 2020.
HLW	High Level Waste.
IAEA	International Atomic Energy Agency.
ICRP	International Commission on Radiological Protection.
IGD-TP	Implementing Geological Disposal Technology Platform.
IKMS	Integrated Knowledge Management System.
ILW	Intermediate Level Waste.
INES	International Nuclear Event Scale.
IRS	Incident Reporting System.
JOPRAD	EC Project - Towards a Joint Programme on Radioactive Waste Disposal Project.
JOPRAD Partners	Organisations who are part of the core JOPRAD Project group, contracted to the EC.
JOPRAD Participants	Organisations which have also been involved in different Working Groups throughout the JOPRAD Project who have been involved in the JOPRAD Project.
JPNM	Joint Programme on Nuclear Materials.
JRC	Joint Research Centre.
LAP	Less Advanced Programme defined as a 'Member-States with early-stage RWMD programme'.
LLW	Low Level Waste.
LUCOEX	EC Project – Large Underground Concept Experiments.
MELODI	EC Project - Multidisciplinary European Low Dose Initiative.
MIND	EC Project – Microbiology in Nuclear Waste Disposal.
MODERN	EC Project - Monitoring Developments for Safe Repository Operation and Staged Closure.
MODERN 2020	EC Project - Monitoring Developments for Safe Repository Operation and Staged Closure.
NEA	Nuclear Energy Agency.
NF-PRO	EC Project - Near Field Processes.
NTW	Nuclear Transparency Watch.
NUGENIA	NUclear GENeration II & III Association
OECD	Organisation for Economic Co-operation and Development.
PEBS	EC Project – Long-term Performance of Engineered Barrier Systems.
RD&D	Research, Development and Demonstration.

RE	Research Entity.
RECOSY	EC Project – Redox Phenomena Controlling Systems.
REDUPP	EC Project – Reducing Uncertainty in Performance Prediction.
SITEX	EC Project - Sustainable network for Independent Technical EXpertise.
SKIN	EC Project - Slow processes in close-to-equilibrium conditions for radionuclides in water/solid systems of relevance to nuclear waste management.
SNETP	Sustainable Nuclear Energy Technology Platform.
SRA	Strategic Research Agenda.
THMC	Thermal Hydro Mechanical and Chemical.
TSO	Technical Support Organisation.
URL	Underground Research Laboratory.
WIPP	Waste Isolation Pilot Plant.
WMO	Waste Management Organisation.

1. Introduction

1.1 Joint Programming on Radioactive Waste Management and Disposal

The overall aim of the Joint Programming process is to pool national research efforts, where the potential for collaboration has been identified. In the field of radioactive waste management and disposal, the benefits of this initiative are five-fold:

1. To improve the effectiveness in the use of European research, development and demonstration (RD&D) resources to tackle common challenges in key areas[1];
2. To deliver scientific excellence through the use of internationally leading Member State expertise and facilities;
3. To develop knowledge management tools, strategic studies, good practice, and transfer of knowledge to ensure the knowledge that has been generated over the past decades in waste management and disposal RD&D, as well as experience from the implementation of disposal programmes, is appropriately distilled, documented, maintained and kept accessible for future generations of experts;
4. To support the development of radioactive waste management and disposal capabilities in Member States with early-stage RWMD programme; and
5. To promote the accessibility of information and to improve the involvement of Civil Society.

A driver for moving towards Joint Programming is Directive 2011/70/EURATOM (the "Waste Directive"), which aims to establish a Community framework for the responsible and safe management of spent fuel and radioactive waste [1]. The Waste Directive reaffirms the ultimate responsibility of Member States for management of spent fuel and radioactive waste generated in their respective countries. This includes establishing and maintaining national policies and frameworks, and implementing these policies by establishing and implementing National Programmes. The activities within the forthcoming Joint Programme provide support for implementation of the Waste Directive with respect to Expertise and Skills (Art. 8), Transparency (Art. 10) and R&D (Art. 12.1(f)).

1.2 The 'Towards a Joint Programme on Radioactive Waste Disposal - JOPRAD' Project

Following several years of discussion and development, the 'Towards a Joint Programme on Radioactive Waste Disposal - JOPRAD' Project was established in 2015 with the objective of completing initial preparatory work for the potential setting up of Joint Programming on radioactive waste disposal, the scope of which has since broadened to cover radioactive waste management and disposal so that it also captures related pre-disposal activities. Such Joint Programming would bring together, at the European level, those aspects of RD&D activities required within national research programmes where synergy from Joint Programming has been identified. JOPRAD brings together a sub-set of "nationally mandated actors" in research: (i) **Waste Management Organisations** ("WMOs")[2], (ii) Regulatory **Technical Support**

[1] http://ec.europa.eu/research/era/what-joint-programming_en.html

[2] The WMOs are represented in the JOPRAD project through the Implementing Geological Disposal Technology Platform (IGD-TP) which is the collaborative body which coordinates RD&D needs of the implementers of geological disposal at the European level (http://www.igdtp.eu/)

Organisations (“TSOs”)[3], and (iii) **Research Entities** (“REs”)[4]. The three steps of the project are:

1. **Engaging Member States on Joint Programming:** Considering the central role of the governmental body to implement the Council Directive (2011/70/EURATOM) in their respective countries, and in collaboration with the EC, JOPRAD has sought to engage in discussion with Member States’ representatives in order to develop an appropriate joint programming management structure. The intent is that this will facilitate National Programmes to finance and carry-out activities jointly where there will be added value at the European level, compared with conducting activities at the national level.
2. **Building on Existing Networks, Programmes and Initiatives to Bring Clear Added Value:** Identifying existing (or developing) research programmes or research agendas that could contribute to the identification of common scientific objectives and activities that the “mandated actors” wish to develop in the Joint Programme.
3. **Agreeing a Long-term Common Vision, Strategic Research Agenda and Roadmap:** Drafting of a “Programme Document” (this document) providing the scientific and technical basis for the development of coordinated programmes focused on agreed priorities of common interest between WMOs, TSOs and REs. This is complemented by a report entitled “Setting-Up a European Joint Programme on Radioactive Waste Management and Disposal’ which will be published later this year.

In this document, we refer to three different groups as part of JOPRAD: the JOPRAD Partners, the JOPRAD participants and the JOPRAD WG4 members. The JOPRAD Partners include the following organisations:

- Andra, France;
- Bel V, Belgium;
- CNRS, France;
- CVREZ, Czech Republic;
- IRSN, France;
- Joint Research Centre, European Commission;
- MCM Environmental Services Ltd, UK;
- Mutadis, France;
- Radioactive Waste Management, UK; and
- SURAO, Czech Republic.

The JOPRAD participants refer to all other organisations which have also been involved in different Working Groups throughout the JOPRAD Project. The JOPRAD WG4 members are the organisations involved in the formation of this document, as part of the JOPRAD Working Group 4, are listed in Appendix 1.

[3] The TSOs are represented, in the JOPRAD project, through the SITEX project (see, http://sitexproject.eu/). The term “Technical Support Organisation” is a generic term referring to organisations fulfilling an “expertise function” as defined by SITEX members, i.e. carrying out activities aimed at providing the technical and scientific basis for notably supporting the decisions made by the national regulatory body

[4] REs in this context may be nationally funded research agencies and research institutes. Their needs are coordinated within JOPRAD by the French National Centre for Scientific Research (CNRS) (see, http://www.cnrs.fr/).

1.3 Scope of Joint Programming considered by the JOPRAD Project

The JOPRAD project has considered activities for Joint Programming that are related to radioactive waste management and disposal of spent fuel, high level waste (HLW) and intermediate level waste (ILW). The waste classification is based on the IAEA guidance [2] whereby:

- Spent Fuel: Spent nuclear fuel contains significant amounts of fissile material, other actinides and fission products. When spent fuel is removed from a reactor storage pools, it will either be reprocessed, stored for long periods of time, or considered for geological disposal;
- HLW: wastes with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long lived radionuclides that need to be considered in the design of a disposal facility for such waste; and
- ILW: waste that, because of its content, particularly of long lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal.

JOPRAD also considers broader waste management aspects linked with the disposal of the wastes, including[5]:

- Radioactive waste pre-disposal activities, such as waste characterisation, treatment and packaging; and
- Interim storage and transport of radioactive waste.

The scope is necessarily broad, covering predominantly scientific technical studies (i.e. implementation driven RD&D, technology or engineering RD&D). Also considered within the scope is the development of an Integrated Knowledge Management System (IKMS) incorporating cross-cutting issues, such as long-term knowledge management, guidance, strategic studies, and knowledge transfer. Applied multi-disciplinary studies with Civil Society aspects have been considered.

1.4 Participants in Joint Programming

Joint Programming is intended to engage at a European level "**programme owners**" and "**programme managers**". At the highest level, "the programme owners" are the ministries or national/regional authorities in charge of the setting up of the national programmes addressed in the Waste Directive. In the JOPRAD project, where the technical part of the research and development programme associated with the national programme is considered, the "programme owners" are the responsible national or regional authorities and "programme managers" are national actors of research ("mandated actors"). They are financing and/or organising RD&D on radioactive waste management and/or disposal in their respective countries. The participation of Programme Managers has to be mandated by the responsible national or regional authorities.

Prior to the start of the JOPRAD Project, the Joint Research Centre (JRC) carried out a study based on available public information in order to identify in the 28 EU Member States (and

[5] JOPRAD did not consider e.g. transmutation, decommissioning, environmental remediation, etc. This does not foreclose extension of the scope in future Joint Programming. In JOPRAD, surface disposal is not excluded, but it is assumed that it does not require specific RD&D and can be addressed within a common IKMS.

Switzerland) the governmental bodies (e.g. ministries), the waste management organizations, and the other entities currently organising and/or funding RD&D on radioactive waste management, along with their respective RD&D objectives. This activity was continued by the JOPRAD project by contacting (with the help of EC Directorate General -RTD (Research and Innovation) services) the Member States' European Atomic Energy Community (EURATOM) Delegates to the Fission Committee [3].

Identification of nationally mandated actors (referred to hereafter as Actors) was based upon information provided by national authorities (authoritative sources) such as the latest Joint Convention[6] reports that were drafted and published by the Member States for the 2012 review meeting of the Contracting Parties, and the NEA/OECD country reports which disseminate information provided by national authorities. Actors fall into three categories: (i) WMOs, (ii) TSOs, and (iii) nationally funded REs involved in the RD&D of radioactive waste management, under the responsibility of the Member States.

In addition, different Interest Groups have been identified during JOPRAD. These include Member States with early-stage RWMD programmes, **Civil Society**[7] and **Waste Producers**[8].

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".

JOPRAD partners (through the European Commission) liaised with Member State representatives on the objectives and benefits of the possible Joint Programming. Member States were then invited to mandate the organisations who may take part in Joint Programming. A Mid-Term workshop was held in Prague in September 2016 to provide a forum for discussion amongst the decision-makers of national research programmes across Member States and the European Commission on the different options for jointly establishing and implementing a Joint Programme. The Member States' representatives and their identified programme owners/managers will also be invited to the JOPRAD final workshop in November 2017 in Prague.

1.5 Vision for Joint Programming

A Vision statement for Joint Programming on radioactive waste management and disposal has been developed by JOPRAD participants:

"A step change in European collaboration towards safe radioactive waste management and disposal through a credible and sustained science and technology programme fostering mutual understanding and trust", which includes:

- A consensus programme between technical support organisations, implementers and researchers throughout the decades covering the development and operation of radioactive waste management and disposal facilities;

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[6] Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management: the Convention calls for review meetings of Contracting Parties. Each Contracting Party is required to submit a national report to each review meeting that addresses measures taken to implement each of the obligations of the Convention.

[7] Civil Society here is a group of representatives of the European Civil Society Organisations. The group is a gathering of 35 organisations from 18 different countries in Europe.

[8] Waste Producers have been identified within JOPRAD as an Interest Group, and have been engaged via dissemination and consultation activities.

- Enhancing the understanding of the risks and uncertainties; and
- Ensuring societal visibility and transparency of research, development and demonstration.

1.6 Boundary Conditions and Strategic Objectives for Joint Programming

A number of boundary conditions and strategic objectives have been derived from the JOPRAD documents outlining the key priorities of WMOs, TSOs and Research Entities [4, 5, 6]:

- **Maintenance of Independence** – It is possible for different Actors with different roles to work together, without prejudice to their own role in the national regulatory process. Most important is the independence between the "expertise function" (TSOs and Research Entities) and the "implementing function" (WMO). Different parties (WMOs and TSOs in particular) can have common agreement of what RD&D should be done and how, and can collaborate in the oversight of that research, but must take their own view on the interpretation of results and data generated [7];
- **Transparent Governance** – A transparent, balanced and efficient mode of governance, taking into concern all participants (including Civil Society) is a prerequisite of joint research between WMOs, TSOs and REs;
- **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 [8]) and reducing uncertainties through excellence in science. Research actions are guided by a long-term vision, as required by the European Commission [1];
- **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 not exceed a clearly defined maximum percentage (including ongoing legal, EC admin., etc.) versus money spent on the science and demonstration (e.g. administration should not exceed 10% of total costs and should preferably be lower);
- **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 Programming is complementary to RD&D activities which will continue to be undertaken nationally or jointly outside of the auspices of Joint Programming where required;
- **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 Joint Programming is a distinct change from past work (and other collaborative working) on radioactive waste management and geological disposal. Translating the societal challenge of radioactive waste management and disposal into operational reality requires the generation of new knowledge, combined with the maintenance and transfer of existing knowledge.

1.7 Status of this Programme Document

This Programme Document predominantly comprises a Strategic Research Agenda (SRA) presented in Section 5. It incorporates the priorities of common interest between WMOs, TSOs and REs and forms the scientific and technical basis of a future Joint Programme. It represents a 5-10 year 'snap-shot' in time[9]. It is foreseen as an input to the setting up of a Joint Programme.

This Programme Document has been drafted by the JOPRAD Project Working Group 4 participants and has been disseminated to the Actors whose input so far is the basis for the present draft. This Programme Document has been disseminated for open consultation via publication on the JOPRAD web page and updated to address comments from the consultation prior to final issue to the European Commission in November 2017.

[9] Although it is noted that a Joint Programme may run for longer than this.

2. Actors and Interest Groups

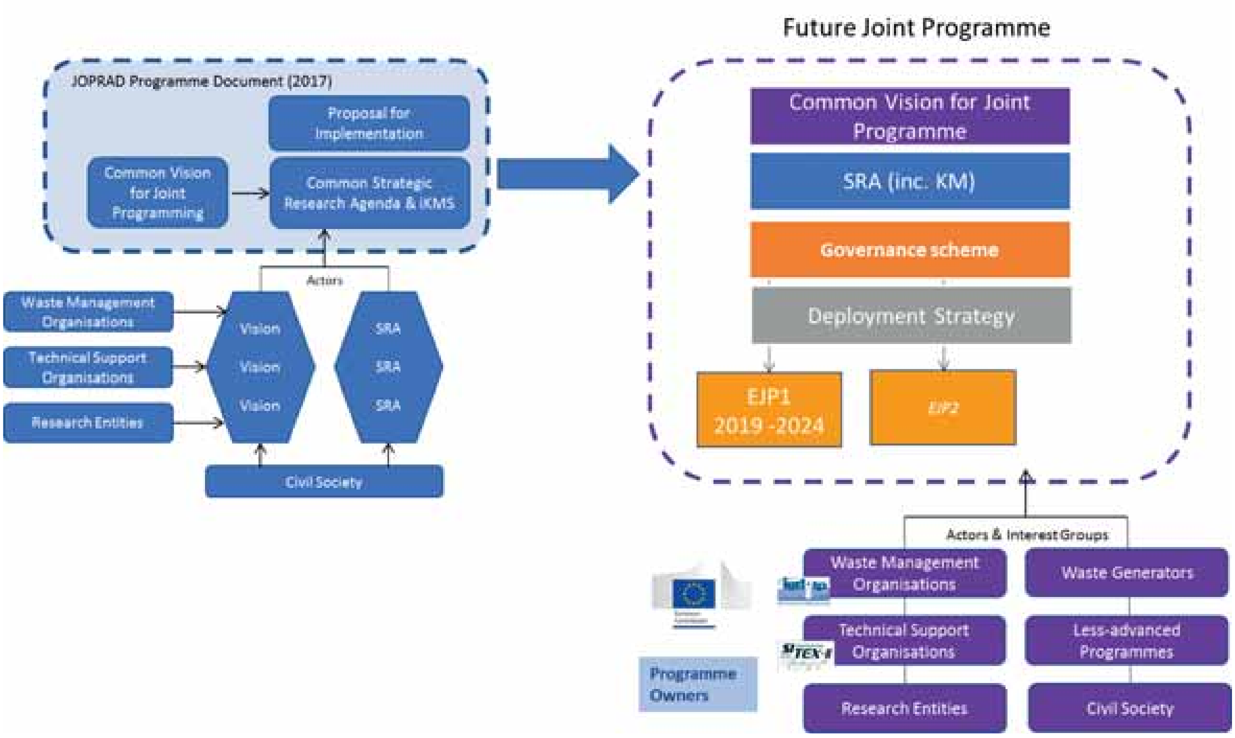
Geological disposal of spent fuel and HLW has been the primary focus of EU funding under the EURATOM Research and Education Programme over the past decades. EURATOM funding was initially based around RD&D contracts on safety issues and underlying science with single research organizations. Governance was achieved through the setting up of contractual arrangements with consortia of research organisations and extending the scope to include the direct involvement of stakeholders in geological disposal projects. Further progress was made when WMOs organized themselves into the Implementing Geological Disposal Technology Platform (IGD-TP), providing advice on the content of the calls through their Strategic Research Agenda [9] and Deployment Plan [10]. In parallel, an independent network of TSOs, the Sustainable network for Independent Technical EXpertise (SITEX) was formed in order to ensure independent technical expertise in the field of safety of geological disposal of radioactive waste. SITEX have now developed a final version of their SRA as input to the JOPRAD project [5]. In addition, as part of the JOPRAD project, a network of REs has been established and they have developed an SRA defining their specific research priorities [6].

The role of Actors and Interest Groups in developing the JOPRAD programme document and potential participation in Joint Programming is described in Figure 1. Within JOPRAD, aspects reflecting interests of Civil Society have been identified by experts, and were introduced to the project via the TSO SRA (SITEX), which specifically considered stakeholder engagement, recognising the importance of addressing social and citizen sciences in research programmes dedicated to radioactive waste management. In a future Joint Programme, the mechanism for explicitly incorporating Civil Society, Member-States with early-stage RWMD programme [10] and Waste Producer inputs could be made via external stakeholder groups or dedicated Interest Groups. At present, it should be noted that they have not been comprehensively considered during development of the JOPRAD SRA.

Within the JOPRAD project, the WMOs, TSOs, REs and Civil Society experts have identified scientific and technical activities that they have prioritised individually in their different SRAs as suitable for Joint Programming, as well as cross-cutting activities. These inputs were then jointly considered and prioritised as a basis for this document, as described further in Section 4. The expectations and priorities of the different actors are also addressed in detail in the "Conditions for implementing a Joint Programme" [7].

[10] A special role will be given in Joint Programming to knowledge transfer from the more advanced to the less advanced programmes. Besides technical/scientific knowledge, experience gained by some countries in setting up decision making processes is of interest, in particular, how to ensure the development and maintenance of necessary skills and the establishment of safety approaches to building a safety case [10]. The engagement of less advanced programmes in Joint Programming was the main objective of the Regional Meeting held in May 2016 in Bucharest.

Figure 1: Scope and participants of the JOPRAD Project (left), scope and anticipated participants of the Joint Programme (bottom right), and outline of a Future Joint Programme (top right).



2.1 Technical Support Organisations

The general objective of SITEX is to develop, at the international level, high quality and independent expertise in the safety of radioactive waste management and geological disposal of radioactive waste. The objective of the SRA produced by SITEX-II [5] is to identify and prioritise the needs for competence and skills development of the expertise function, at the international and the European level. This was based on a transparent methodology and takes into consideration the different states of advancement of radioactive waste management and geological disposal programmes and the concerns of Civil Society. The scope of the SRA covers all the topics relevant to the expertise function of TSOs, namely to assess whether geological disposal facilities are developed and will be constructed, operated and closed in a safe manner. Therefore, topics related to pre- and post-closure safety as well as to the technical feasibility of geological disposal are considered most important.

The scope of the SITEX SRA includes actions dedicated to radioactive waste pre-treatment, treatment and conditioning, as well as transport and storage which impacts on the safety of geological disposal facilities. However, the first version of the SITEX SRA was specifically focused on disposal in underground facilities. Since predisposal management of radioactive waste and spent fuel is considered as a key main topic by TSOs, associated topics were also identified in the framework of the JOPRAD project for inclusion in the Programme Document [11].

The independence of the regulatory function calls for the support of an independent expertise function that develops and maintains the necessary knowledge and skills in the field of nuclear safety. The expertise function's RD&D objectives may differ from those adopted by the WMOs. However, there are activities of interest to the expertise functions that overlap to a significant extent with the RD&D activities performed by the WMOs.

The regulatory function (safety authorities, regulators) supported by the expertise function(s) (technical support organisations, universities, research institutes, commercial organisations), assesses the safety case prepared by the operators and regulates the development, operation and closure of disposal facilities.

2.2 Research Entities

The goal of the REs SRA [6] in European Joint Programming is to develop a long-term vision on an integrated fundamental scientific understanding for all concepts related to the disposal of long-lived intermediate level and highly radioactive waste and spent nuclear fuel in geological disposal facilities within Europe, including all aspects of storage, transport and final disposal. European Joint Programming must therefore aim to support disposal implementation programmes at all stages of advancement, through scientific excellence and leading-edge research on basic components and generic processes. The outcomes will be oriented towards developing understanding and tools which can be applied to analysing the evolution of complex site-specific systems in support of long-term safety[11].

Through this goal, individual Member States will be supported in providing assurance to the expert community, Actors involved in the implementation of geological disposal projects, decision makers and the public, that geological disposal of radioactive waste is underpinned by the best science available at the time. REs consider first and foremost safety from a scientific-technical point of view, and contribute to a scientific assessment basis that is reliable and sound. The REs' SRA may be useful for individual Member States and research organisations when

[11] Throughout this document, 'long-term safety' implicitly refers to long-term safety including environmental protection.

deciding upon their own RD&D programmes. For Joint Programming the REs' SRA has been used as a basis to identify common RD&D issues between WMOs, TSOs and REs.

2.3 Waste Management Organisations

The Implementing Geological Disposal of Radioactive Waste Technology Platform's (IGD-TP's) work is driven by ten waste management organisations and one governmental body, that share a common vision that *"by 2025, the first geological disposal facilities for spent fuel, high-level waste, and other long-lived radioactive waste will be operating safely in Europe"* (Vision 2025).

The IGD-TP's SRA [9] is aimed at identifying the main RD&D issues that need a coordinated effort over the next years in order to achieve Vision 2025. The SRA did not identify a need for cooperative work on research and other topics such as siting or radioactive waste inventory evaluation, as these areas are advanced in programmes close to implementation. Nevertheless, experienced feedback from such work represents a vital link between the programmes closest to licensing and those which are currently at earlier stages in their implementation of geological disposal programmes.

Because the IGD-TP SRA identifies the key topics of RD&D that have the greatest potential to support geological disposal implementation through enhanced cooperation in Europe, it also provides valuable input in identifying topics for future calls for proposals issued by the EC framework programme. The SRA is well suited to this role as many of the topics have been established collectively through discussions among many European WMOs and are of interest to IGD-TP members. Indeed, the IGD-TP SRA is focussed on developing areas of geological disposal facility safety and technological development through the combined use of resources, which represents a major objective of the EC framework programme.

The IGD-TP SRA was created with the intent of creating synergies, co-operation and co-ordination, both internally between the IGD-TP participants and with external activities that take place in other technology platforms and within other international fora.

The state of development of the waste management programme is not homogeneous amongst Member States; some countries are at or close to license application, such as, Finland, Sweden and France, and at the opposite end of the disposal spectrum there are several New Member States whose deep geological disposal programmes are in the very early stages and no systematic research programmes exist (such as Croatia, Italy, Lithuania, Poland, Romania, Slovenia, Slovakia). In these cases, the disposal concept is only generic and in most of these countries needs updating, taking into account the current socio-economic context. The exceptions are the Czech Republic and Hungary, which have already initiated siting processes.

2.4 Civil Society

The socio-political dimension is a critical aspect to the successful implementation of safe radioactive waste management and disposal. In the context of this project, "Civil Society" is defined as a group of representatives of the European Civil Society Organisations (CSOs), involved in radioactive waste management activities at EU or national level. This group has interacted with JOPRAD participants throughout the project via Working Group 3. It represents 35 organisations from 18 countries in Europe. This Civil Society group has been assembled under the auspices of the Working Group for Radioactive Waste Management of the Nuclear Transparency Watch (NTW) network, in cooperation with MKG (Swedish NGO Office for Nuclear Waste Management Review). Strengthening and maintaining a high level of nuclear safety in Europe is a common concern for all members of this group without prejudice to their position with regards to nuclear energy.

Within the JOPRAD project, experts have been engaged to establish the expectations and views of Civil Society regarding the conditions and means for setting-up a Joint Programme and regarding their potential involvement in the governance of a future Joint Programme.

Within this Programme Document and drafting of the JOPRAD SRA, socio-political themes proposed by Civil Society experts have been considered for inclusion and, where possible, have been integrated with technical sub-domains. Additionally, potential mechanisms for interacting with Civil Society on the identified RD&D activities of common interest between the TSOs, WMOs and REs are identified. A guide for the evaluation by Civil Society of potential governance patterns of RD&D for European Joint Programming on Geological Disposal has been published through JOPRAD [12].

2.5 Waste Producer Organisations

Although not formally an Actor in the JOPRAD project, waste producer organisations have been involved in the later stages via the NUclear GENeration II & III Association (NUGENIA). NUGENIA is an association, including members from 26 countries, dedicated to the research and development of nuclear fission technologies, with a focus on Generation II and III nuclear plants. It aims to be an integrated framework for R&D to ensure safe, reliable and competitive Gen II & III fission technologies, which:

- Fosters collaboration between industry, SMEs, research organisations, academia and technical safety organisations;
- Builds knowledge and expertise;
- Generates R&D results with added value for the nuclear community.

Although involved late in the project, NUGENIA's contribution has been valuable and sets a foundation for future collaboration in projects influencing the wasteform for final disposal.

3. Integrated Knowledge Management System (IKMS) of a future Joint Programme

3.1 Objectives, Scope and Audience

3.1.1 Objectives

It is essential that cross-cutting activities are established in order to implement an efficient and integrated Knowledge Management programme at EU level in order to meet the following objectives:

Preservation / capitalisation of generated knowledge: Ensure that the public knowledge generated over the past, ongoing and future RD&D activities is preserved and made accessible for application by the target audience (see Section 3.1.3).

Member-States with more advanced programmes have acquired over the past decades specific experience, know-what and know-how on how to establish a national RD&D programme for the safe management of spent fuel and radioactive waste.

Transfer of scientific-technical knowledge: To a broad set of Actors, including Member-States with early-stage RWM programme. This challenge includes ensuring that Member-States with national programmes at an early-stage of implementation can take advantage of existing knowledge and know-how from past and on-going activities, projects and programmes.

Transfer of knowledge between generations: Given the long duration of RWM programmes, the generation of scientists involved since the early phase of RD&D programmes are retiring. This is therefore essential for the organisations to manage the existing and forthcoming knowledge in such a way that present and future professionals entering the field of RWMD can benefit from this knowledge, i.e. that the knowledge is not lost with professionals retiring or moving to other fields.

Therefore, the objective is to 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 radioactive waste management and disposal by providing training and mobility for researchers.

***Dissemination of knowledge*:** To disseminate knowledge and demonstrate progress, results and added-value of the European Joint Programme to a wide audience.

3.1.2 Scope

In this context, we define 'knowledge' as the scientific and technical knowledge generated in RD&D activities in radioactive waste management; the experience, know-what and know-how of the Member-States around the development and implementation of a R&D national programme, as well as experience from the implementation of disposal programmes. This incorporates notable scientific and technical knowledge generated over the past collaborative research activities at the European level (e.g., collaborative projects funded within the EURATOM Research and Training programmes: i) under FP6, FP7 (BELBAR, CARBOWASTE, CAST, CATCLAY, DOPAS, FIRST-NUCLIDES, FORGE, LUCOEX, MODERN, PEBS, RECOSY, REDUPP…), ii) under H2020 (Cebama, MIND, Modern2020, BEACON, CHANCE, DISCO and THERAMIN), iii) future projects to be carried out within the forthcoming Joint Programme, and iv) any relevant and publicly available knowledge, including the relevant science base).

3.1.3 Target Audience

The outcome of such activities will be of interest for:

- Scientists and experts entering into and working in the field of RWMD in general, and especially for the Member-States that are at an early stage in the development of their national programme, in order to avoid duplication of RD&D work and make the best use of resources, this includes the experts reviewing safety assessment, safety cases and license applications;
- Policy and decision-makers, including those required for building the necessary R&D, expertise and skills, and transparency programmes is Member States at less advanced implementation stages; and
- Broader interested community (incl. NGOs involved in RWM, local stakeholders…).

3.2 Knowledge Management – Expected Impacts

If efficient, the integrated Knowledge Management System will:

- Contribute to bridge the risk of shortage in skills /competences in view of the long lead-times and operational time-spans for RWMD,
- Facilitate transfer of acquired scientific and technical public knowledge between Member-States at different stages of advancement in the implementation of their national RWM programmes,
- Lead to an efficient use of the RD&D resources at the European level by sharing and advancing existing knowledge rather than repeating and duplicating RD&D work,
- Provide the potential for a commonly accepted knowledge base for implementation and assessment; and
- To a larger extent, such integrated knowledge management will contribute to the responsible and safe management of radioactive waste, in particular in view of the long implementation time schedules for disposal of spent fuel and high-level waste. This is also an important aspect of the Member-States implementing their obligations under the Waste Directive.

3.3 Foreseen Knowledge Management Activities

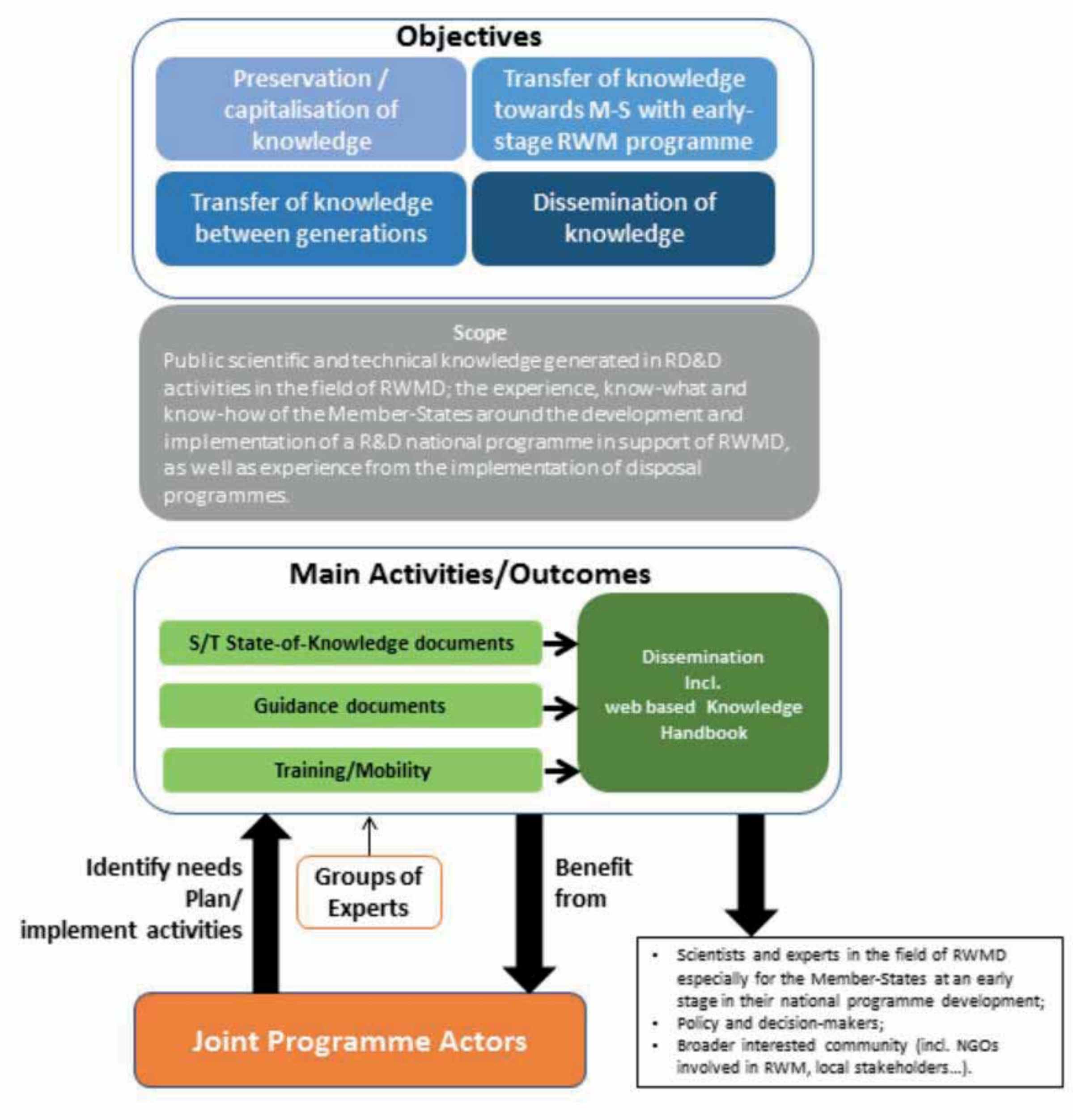
In order to meet the objectives listed above, the Knowledge Management activities shall consist of i) producing **scientific and technical State-of-Knowledge Documents** as an intelligent synthesis for specific scientific and technical topics in the field of RWMD, ii) developing **guidance documents** for planning and implementing research in support of the development of radioactive waste disposal solutions, iii) establishing a training portfolio, delivering **scientific and technical training courses** and fostering **researchers' mobility**.

At the EJP level, the overall approach is to make use, where possible, of existing activities, projects, international organization initiatives, training opportunities, etc. without duplicating them. Links with existing activities should be made as soon as it is possible.

All the outcomes of these Knowledge Management activities (State-of-Knowledge Documents, Guidance Documents, Training Materials) as well as the outcomes of past, ongoing and future RD&D and networking activities (deliverables, publications, reports…) will be preserved and made accessible on a public **web-structured Knowledge Management platform in view of their preservation/capitalisation/transfer and dissemination**. JRC offers to host such a Knowledge Management System web platform (open access). Hosting of the Knowledge

Handbook on a separate WiKi platform, with linking to the KM Platform would enable a transparent and flexible implementation of the Knowledge Handbook.

Figure 2: Knowledge Management System objectives, scope and main outcomes.



3.4 Future implementation of the IKMS component of the Joint Programme

Preparatory work has been carried out within the JOPRAD project to consider how implementation of the IKMS component of the Joint Programme could be practically achieved [13]. The basis of this document is that the IKMS activities are specified and managed by supporting Actors, with the administrative framework provided and hosted by the European Joint Research Centre (JRC). Preparatory work (described further in Section 6) to set-up a Joint Programme includes the formation of a dedicated working group which will continue to develop the terms of reference for ensuring such knowledge management activities are integrated, within the overall framework of the Joint Programme governance scheme. Common topics of interest for the IKMS area have been identified, following the methodology outlined in Section 4, and are described in further detail in Section 5.

4. Methodology for identifying the scientific and technical basis of the Strategic Research Agenda (SRA)

4.1 Introduction

Within Work Package 3 of the JOPRAD project, working groups were established for TSOs, WMOs and REs. The work done here for the Joint Programme is based on the outcomes of these working groups. The WMOs, TSOs, REs and experts from Civil Society have worked together to identify different activities that could be part of a future Joint Programme. Within the different activities considered, the actors participating in JOPRAD have indicated their preferences and priorities based on their own perceived needs. Within Work Package 4 a step-wise process has been used to further define and prioritise the scientific and technical domains of common interest which are proposed in the Strategic Research Agenda (SRA) contained in Section 5. This has included the following 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 the 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 SRA;
2. **Surveying Representative Joint Programme Actor 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 Actor 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 SRA. 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 SRA 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 SRA within the broader European radioactive waste management and disposal community. Obtaining feedback and end-user input to facilitate updating of the final SRA.

4.2 Step 1: Compiling Activities for Inclusion

4.2.1 Scope of the JOPRAD SRA

As previously specified in Section 1.3, from the activities suggested by the Actors participating in the JOPRAD project (WMOs, TSO and REs), the scope includes the following technical and scientific aspects of radioactive waste management and disposal, which are the focus of Section 5 (the JOPRAD SRA):

- Radioactive waste characterisation, treatment and packaging;
- Interim storage and transport of radioactive waste; and

- Geological disposal of spent fuel, HLW and ILW[12].

Socio-political themes have also been captured within the JOPRAD SRA and are discussed further in Section 6. Recognising the complex nature and long-term dimension of safe radioactive waste management and disposal, successful implementation requires integration of the technical and scientific basis within a broader socio-political framework. Therefore, dedicated themes have been identified for consideration in the future Joint Programme, based on their relevance to specific technical projects. It is anticipated that the Joint Programme would not include separate projects on socio-political themes, but that technical and scientific projects, derived from the scope descriptions in Section 5, may include specific tasks related to socio-political aspects if they are complementary to the technical objectives. This approach has worked well in recent EC Projects (e.g. the Modern2020 project, which has included a specific work package on effectively engaging local stakeholders in RD&D on monitoring for geological disposal).

4.2.2 Structure and terminology of the SRA

To appropriately structure, group and communicate suggested activities, they have been categorised into three different levels:

- Level 1 Strategic Themes;
- Level 2 Domains;
- Level 3 Sub-Domains.

To simplify this structure, all of the strategic themes, domains and sub-domains have been numbered i.e. Strategic Theme 1, Domain 3, Sub-Domain 1 would be 1.3.1.

The definitions of the Strategic Themes, Domains and Sub-Domains are presented in detail in Section 5. To avoid conflict with terminology used elsewhere, or with what might eventually be used within the actual Joint Programme, it was agreed to avoid the use of: Project; Topic; Task; or Area.

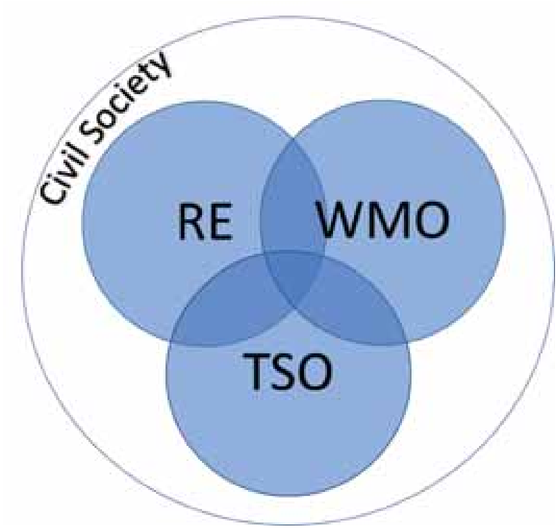
Within the sub-domains identified in the JOPRAD SRA, specific activities indicated as being ‘implementation driven’ refers to applied science and technological developments critical for implementing safe radioactive waste management and disposal.

4.2.3 Compilation of activities suggested for Joint Programme by the WMO, TSO and RE SRAs

In the first instance the RD&D activities suggested for inclusion within a future Joint Programme by each of the actors were compared, and activities of common interest between the respective SRAs of two or more of the JOPRAD working groups used as the basis for a first compilation (as represented by the darker central shaded areas of overlap in Figure 3). The activities suggested at this step totalled over 150 individually identified RD&D needs or cross-cutting activities. Also included and considered was the inclusion of activities co-developed between the SITEX working group and representatives of Civil Society, ensuring that those technical, scientific or engineering activities with social science facets were accounted for and clearly visible.

[12] In JOPRAD, surface disposal is not excluded, but it is assumed that it does not require specific RD&D and can be addressed within the IKMS

Figure 3: Representation of common areas of interest for Joint Programming.



As per the structure and definitions presented in Section 4.2.2, this first compilation of activities was organised by strategic theme, domain and sub-domain, with clear reference to each of the suggested activities' origin (i.e. the WMO, TSO, or RE SRA). This process underwent several iterations in successive Work Package 4 meetings.

4.3 Step 2: Surveying Representative Joint Programme Actor Views

Once the first compilation was prepared, it was recognised by the Work Package 4 Working Group, that this did not represent an exhaustive list of all the potential activities that could enter into the scope of a potential future Joint Programme. It simply indicated activities for which a sufficient level of common interest has been expressed among the JOPRAD contributors. Therefore, it was considered necessary to obtain broader input by means of a questionnaire, primarily to further refine the compilation, identify any gaps and understand individual organisations' priorities against each activity.

A questionnaire was subsequently issued to each of the organisations involved with the original WMO, TSO and RE working groups, and to all organisations identified as 'potential mandated actors' within JOPRAD Working Group 2. A full list of the organisations issued with the questionnaire is outlined in Appendix 2. The questions were framed to understand each organisations own individual priorities and to establish:

- Clear drivers for each RD&D activity – if they considered it implementation-driven or driven by enhanced understanding of the underlying science;
- Where IKMS activities would be beneficial;
- Timescales of interest – high interest for 2019-2024, or beyond; and
- Financial/in-kind support – their interest to participate by providing a financial contribution or effort in-kind, versus interest supporting the steering of a project (i.e. as an end-user).

37 individual organisations responded to the questionnaire, representing 16 European countries in addition to the European Joint-Research Centre (JRC).

Table 1: JOPRAD WP4 Questionnaire Responders (organised by country and type of organisation)[13]

Country	WMO Organisation	TSO Organisation	RE Organisation
Belgium (BE)	ONDRAF/NIRAS	BelV	SCK.CEN
Czech Republic (CZ)	SURAO	CVREZ	CTU
Finland (FI)	POSIVA		
France (FR)	ANDRA	ISRN	4 Combined (CEA, CNRS, UPMC, BGRM)
Germany (DB)	BfS; BMWi	GRS	HGF
Hungary (HU)	PURAM	TSE	
Italy (IT)	SOGIN		Combined
Lithuania (LT)		CPST	LEI
Netherlands (NL)	COVRA	NRG	TNO
Poland (PO)			PGI
Slovakia (SK)		DECOM	
Slovenia (SO)	ARAO		
Spain (ESP)	ENRESA	CIEMAT	CIEMAT
Sweden (SE)	SKB		
Switzerland (CH)	NAGRA		PSI
United Kingdom (UK)	RWM		
TOTAL	**14**	**9**	**14**

4.4 Step 3: Identifying Priorities and Activities of High Common Interest

The questionnaire responses were collated and, using the data and information received (and after some merging of common topics), the compilation of ~92 activities was screened using the following method to identify priorities and to confirm the activities of high common interest:

1. The number of responder organisations indicating an activity as 'high' or 'medium' interest for the period 2019-2024 was totalled for each Actor group (i.e. for TSOs, WMOs, and REs);
2. The 'High' and 'Medium' votes for the activities were then weighted (using a score of 1 for 'High' and 0.5 for 'Medium') and normalised to account for the total number of organisations which voted from each Actor Group. The scores from each Actor group

were then totalled, resulting in a combined score for each activity of between 0 and 18 (0 being lowest priority and 18 being the highest);

3. Using the range of 0-18, each activity was subsequently ranked with an overall ‘Level of Common Interest' of High, Medium, or Low using the following criteria:
    - >10.01 High;
    - 6.01-10.00 Medium;
    - 0-6 Low.
4. Based on the comments received during the Consultation phase, some of the ‘Level of Common Interests’ were changed based on a transparent methodology, outlined in Section 4.6 below.

Using this method, a total of 63 activities were identified as having a High or Medium Level of Common Interest, with 29 identifying as having a Low Level of Common Interest.

All of these have been grouped into a hierarchy of Strategic Themes, Domains and Sub-Domains which form the scientific and technical basis of the JOPRAD SRA described in Chapter 5. An overview of all 92 sub-domains is provided in Chapter 5, with the sub-domains with a Low Level of Common Interest differentiated by italics and a grey background.

4.5 Step 4: 1st Draft SRA

In addition to identifying the priorities and activities of high common interest, additional data collected from the questionnaire have been used to develop SRA sub-domain descriptions. For each sub-domain, a proforma (see example format in Table 2) is presented to communicate a clear and concise scope definition of what is proposed, including additional context and background.

Table 2: Format and content of Sub-domain tables used in the SRA.

<table>
<tr><th colspan="6">X.X.X (Sub-Domain Number) Sub-Domain Title</th></tr>
<tr><td colspan="3" rowspan="2">Background</td><td colspan="3">Research Needs/Driver</td></tr>
<tr><td colspan="3">Research Objectives</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

4.6 Step 5: SRA Consultation and Finalisation

This Programme Document has been drafted within the JOPRAD project and has been disseminated for open consultation via publication on the JOPRAD web page. The Programme Document was presented at a workshop on 4th April 2017 in London.

This final document has taken into account comments from the consultation and is scheduled for issuing to the European Commission in November 2017. Based on the consultation comments, some of the sub-domains have had their ‘Level of Common Interest’ altered. The methodology for this, and which sub-domains have changed Levels is outlined in Appendix 4.

All of these changes have been incorporated into this document and are reflected in the domain overviews and sub-domain tables.

In addition to changes to existing sub-domains, one new sub-domain was suggested. This has been included as Appendix 5, and will be incorporated into the EJP SRA for future consideration.

5. JOPRAD Strategic Research Agenda for European Joint Programming

Recognising the different types of activities suggested and prioritised by the WMOs, TSOs, and REs for inclusion within the JOPRAD Joint Programme SRA, at the highest level, three Strategic Themes have been considered, each further sub-divided into Domains and Sub-Domains.

The Strategic Themes (1, 2 and 3 in bold) and Domains (bullets) are represented in Figure 5 below. For a complete list of the SRA, including the strategic themes, the domains and the sub-domains please see Appendix 3.

In this Section, each of the domains are described in more detail, including a list of the sub-domains, their level of common interest, and their background, research drive/need, and research objective outlined in the sub-domain tables.

Figure 4: Strategic Themes and Domains of the JOPRAD Joint Programme SRA.

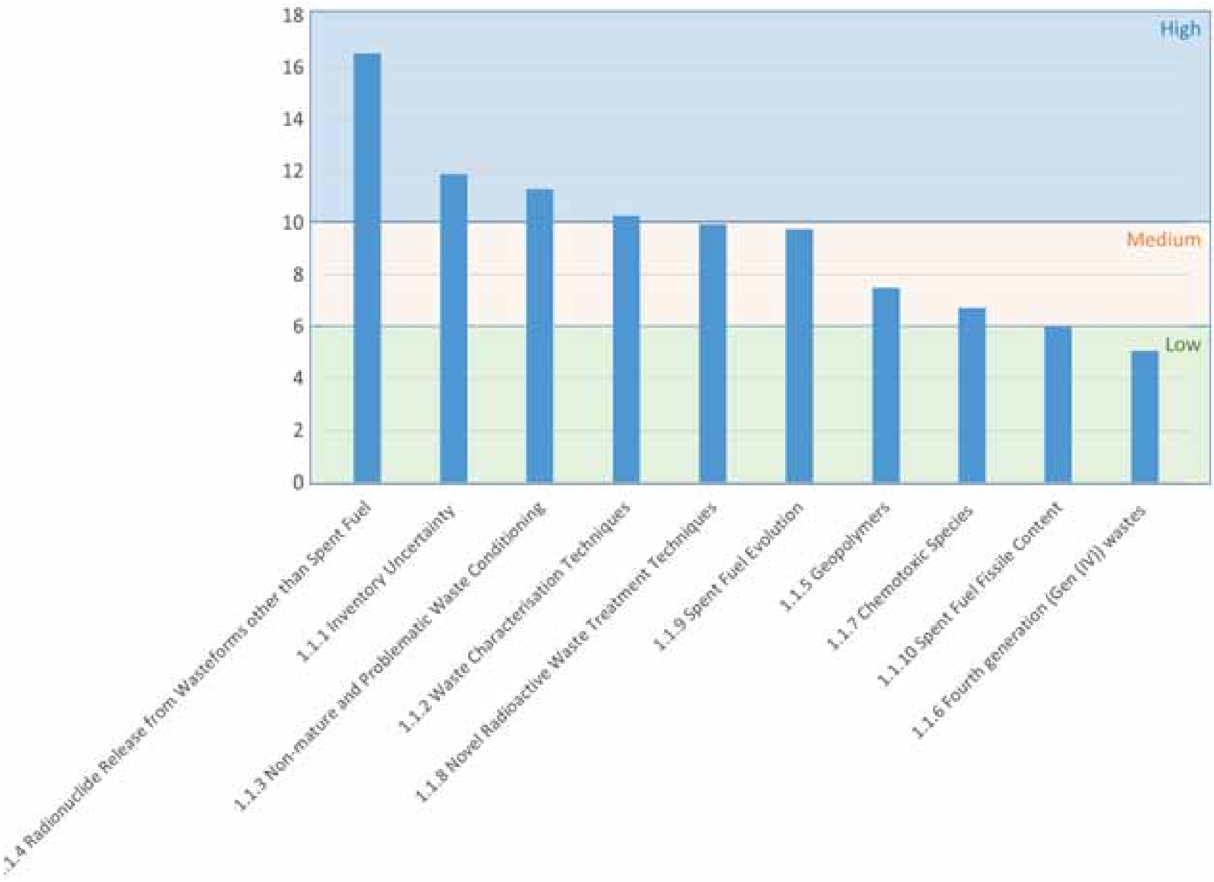
5.1 Strategic Theme 1: Building Understanding

1.1 Inventory, Wasteform and Waste Characterisation

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 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 storage, operational and post-closure phases of a geological disposal facility lifecycle is important both for designing the disposal system and to the associated safety case. This domain comprises RD&D associated with improving this understanding (characterization, conditioning, treatment, radionuclide source-term, etc.). The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The level of common interest for the sub-domains are shown in Figure 5 below.

1.1.1 Inventory Uncertainty;
1.1.2 Waste Characterisation Techniques;
1.1.3 Non-mature and Problematic Waste Conditioning;
1.1.4 Radionuclide Release from Wasteforms other than Spent Fuel;
1.1.5 Geopolymers;
1.1.6 Fourth Generation (Gen (IV)) wastes;
1.1.7 Chemotoxic Species;
1.1.8 Novel Radioactive Waste Treatment Techniques;
1.1.9 Spent Fuel Evolution;
1.1.10 Spent Fuel Fissile Content.

Figure 5: Level of Common Interest for Inventory, Wasteform and Waste Characterisation Sub-Domains.



1.1.1 Inventory Uncertainty					
Background Knowledge of the radionuclide and chemical inventory (including metals and organic compounds) of wastes requiring disposal in a deep geological repository is important for the transport, operations and post-closure safety cases. Data quality of waste inventories is often variable, with uncertainty often dominated by waste heterogeneity. Nevertheless, in general only a small subset of radionuclides will dominate the safety case. Furthermore, where sampling uncertainty is the dominant consideration there is little benefit to be gained from enhancing analytical accuracy. Therefore, an integrated understanding of safety case requirements, inventory and analytical techniques can provide significant benefits. Regarding spent fuel, the EC FIRST Nuclides project aimed to determine 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. ***EC Projects: FIRST Nuclides***				**Research Needs/Driver** Improved understanding of those species that dominate the transport, operations and post-closure safety cases and targeted fit-for-purpose assay can enable cost-effective data quality improvements, providing increased confidence in the safety case. **Research Objectives** To identify good practice in the management of the inventory for disposal.	
Implementation Driven					✓
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High	✓	Medium		Low	

<table>
<tr><th colspan="6">1.1.2 Waste Characterisation Techniques</th></tr>
<tr><td colspan="3">Background
Sufficient knowledge of the waste characteristics is necessary to define suitable treatment, conditioning and disposal strategies. Often, countries need to manage historical radioactive waste without adequate information about their origin and radionuclide content and in some cases wastestreams 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 thermal characteristics of waste packages. The EC CHANCE project “CHAracterization of conditioned NuClear waste for its safe disposal in Europe” has been selected for funding within the Euratom call H2020 2016-2017. The CHANCE project will start in 2017 for a 4-year period. It aims to address the specific issue of the characterization of conditioned radioactive wastes through non-destructive assay. CHANCE objectives are to: 1/establish at the European level a comprehensive understanding of current conditioned radioactive waste characterization and quality control schemes. 2/develop, test and validate techniques already identified that can improve the characterization of conditioned radioactive waste.
EC Projects: CHANCE</td><td colspan="3">Research Needs/Driver
• The development of accurate and cost-effective technologies for the radiological characterization and segregation of small amounts of raw historical radioactive waste is needed in several countries,
• Rapid assay techniques which maintain waste package integrity and containment have the potential to provide quality assurance of packages being stored, transported or received at a GDF. Such techniques would not expose personnel to additional dose, whilst providing reassurance that the waste inventory is as stated in the package description.

Research Objectives
To develop accurate and cost-effective technologies for the radiological characterization and segregation of small amounts of raw historical radioactive waste is needed in several countries,
To develop and demonstrate enhanced or novel non-destructive assay techniques appropriate to radioactive waste package quality assurance measurements.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.3 Non-mature and Problematic Waste Conditioning</th></tr>
<tr><td colspan="2" rowspan="2">Background
Significant progress has been made in the development of robust disposal concepts 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 decommissioning wastes.</td><td colspan="4">Research Needs/Driver
The decommissioning of nuclear facilities across Europe will require the conditioning / packaging of a wide range of problematic wastes. Collaborative research and development and transfer of knowledge between waste producers would enable the cost-effective development of wasteforms appropriate for safe geological disposal.</td></tr>
<tr><td colspan="4">Research Objectives
To share best practice in waste processing, to develop novel waste conditioning / packaging approaches for problematic wastes
Wastes that may require consideration include: sulphonate-based ion-exchange resins (which form expansive phases in cement), high-uranic pond-sludges, highly tritiated wastes, high iodine-129 containing wastes, sealed sources, irradiated neutron reflectors and neutron sources (containing beryllium), nuclear fusion wastes, contaminated mercury, plutonium residues, radium containing wastes from non-nuclear activities, bitumen sludges (swelling due to osmosis and radiolysis), etc.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.4 Radionuclide Release from Wasteforms other than Spent Fuel</th></tr>
<tr><td colspan="2" rowspan="2">Background
The formulation of a wasteform provides the first barrier in a GDF’s multi-barrier system of isolation and containment. Improved understanding of the radionuclide and chemical species release kinetics would reduce uncertainty in the source-term of key species in performance assessments and would enhance confidence in GDF post-closure safety cases.
The EC CAST project (2013-March 2018) will provide understanding of the ^{14}C source term for graphite, activated metals (Zircaloy and stainless steel) and ionic exchange resins.
EC Projects: CAST</td><td colspan="4">Research Needs/Driver
To improve the robustness of the post-closure safety case by increasing confidence in the understanding of the source-term of a range of existing and future wasteforms.</td></tr>
<tr><td colspan="4">Research Objectives
Potential objectives include studies to identify the radionuclide release mechanisms and associated kinetics for the following wastes:
• Vitrified waste (ILW and HLW) - release processes include: fracturing, hydration under unsaturated conditions, interaction with surrounding materials (carbon steel, corrosion products, concrete (including low-pH concretes), clay, etc.), resumption of alteration, influence of irradiation on residual alteration rate, influence of composition, congruency between glass alteration and radionuclide release;
• Metallic wastes: corrosion of reactive metals (aluminium and magnesium alloys, metallic uranium), influence of polymer degradation on corrosion rate, galvanic corrosion, influence of water chemistry (chlorides, nitrates, sulphur species, etc.), biocorrosion;
• High organic content wastes, including bitumen sludges and cemented plutonium contaminated material;
• Graphite: release of ^{14}C (influence of surface to volume ratio, thermal history and pH);
• Release of radionuclides from cementitious waste forms.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.5 Geopolymers</th></tr>
<tr><td colspan="4" rowspan="2">Background
A geopolymer is an inorganic polymer made of long chains of alumino-silicates. They are formed by the dissolution of silica and alumina reactive powders into a high pH solution, rapidly setting to form an attractive wasteform for radioactive waste management due to their likely radiolytic stability in comparison to organic polymers. Geopolymers have similar chemical and physical properties to cements and are viewed as a “green” alternative to Ordinary Portland Cement as they generate less CO_2 in production and can utilise industrial by-products such as Kaolin, Blast Furnace Slag (BFS) and Pulverised Fuel Ash (PFA).
Due to the initial formulation occurring in a liquid state, these materials display low viscosity prior to polymerisation. As a consequence, they may be used to flood grout large or complex items or to achieve high incorporation rates of sludges and slurries during in-drum mixing. Corrosion inhibitors may be used in geopolymer compositions to improve their performance with regard to H_2 production.</td><td colspan="2">Research Needs/Driver
Due to the potential operational benefits of geopolymers (low viscosity, environmentally friendly, low exotherm), there is a need to better understand their performance in the context of geological disposal.</td></tr>
<tr><td colspan="2">Research Objectives
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) in the context of the disposal environment.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.6 Fourth generation (Gen (IV)) wastes</th></tr>
<tr><td colspan="3">Background
Research is ongoing into the next generation of nuclear reactors (supported in the EC by the Sustainable Nuclear Energy Technology Platform, the SNETP). The leading reactor designs are the Sodium Fast Reactor (SFR), the Very High Temperature Reactor (VHTR), the Lead Fast Reactor (LFR), the Gas Fast Reactor (GFR), the Super-Critical Water Reactor (SCWR), and the Molten Salt Reactor (MSR). Although the quantity of radioactive waste generated by these technologies will be less than from previous generations, its properties are likely to differ from current wastes and may present new challenges.
EC Project: SNETP</td><td colspan="3">Research Needs/Driver
Learning from previous nuclear power programmes has demonstrated that early and detailed consideration of waste management and disposal is critical to the technical viability and public acceptability of the technology.

Research Objectives
To understand the nature and quantities of wastes arising from a fourth generation of nuclear reactors, identifying challenges to the disposal of such wastes and enabling early feedback to reactor system designers in order to mitigate associated risks.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">1.1.7 Chemotoxic species</th></tr>
<tr><td colspan="3">Background
Significant focus has been placed on understanding the behaviour of radionuclides in the disposal system and the environment; however, a range of chemical species (e.g. lead, mercury, cadmium, beryllium and organic species) possessing varying degrees of radiotoxicity may also be present in the emplaced wastes.
Further understanding is required, 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.</td><td colspan="3">Research Needs/Driver
Greater understanding of the inventory and behaviour of potentially chemotoxic species is necessary in order to provide confidence in the post-closure safety case and to enable appropriate packaging of waste materials arising from current and future decommissioning operations.

Research Objectives
To improve understanding of the nature and quantities of the likely chemotoxic component of common decommissioning wastes.
To develop improved understanding of the fate of potentially chemotoxic species within the engineered and natural systems of appropriate disposal concepts.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.8 Novel Radioactive Waste Treatment Techniques</th></tr>
<tr><td colspan="3" rowspan="2">Background
The management of some radioactive waste is still a challenge, while for some others there is the potential for optimisation. This could include operational wastes, by-products from existing processes (e.g. sludges), chemically reactive wastes, irradiated-graphite, etc. Radioactive waste treatment processes could be applied to a wide range of waste streams and could provide benefits in terms of Waste Acceptance Criteria, safety demonstration, volume and hazard reduction and cost savings. Some technologies could facilitate the management of waste or facilitate volume reduction, e.g. thermal treatment.
Some projects have already been carried out on this topic, and some are ongoing, e.g. EC Carbowaste, EC CAST and EC THERAMIN.
EC Projects: Carbowaste, CAST, THERAMIN</td><td colspan="3">Research Needs/Driver
Radioactive waste treatment can result in significant volume and/or hazard reduction, and potential cost savings. Such processes can also provide a more stable disposal matrix.</td></tr>
<tr><td colspan="3">Research Objectives
This topic offers the opportunity to extend the work which has been started by Member States, or will enable further optimisation. E.g. concerning thermal treatments, common interests will have been identified within the THERAMIN project, providing scope for further development. Similarly, ^{36}Cl in graphite waste could be removed if promising laboratory studies were extended to the pilot and implementation scales.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.9 Spent-Fuel Evolution</th></tr>
<tr><td colspan="3" rowspan="2">Background
Internationally, considerable effort has been devoted to the long-term consideration of fission product releases from spent fuel that may become exposed to groundwater once its container is breached. Hence, for light-water reactor fuel there is a good understanding. However, for other types of fuel (doped fuel, high burn-up fuel, MOx), and for the consideration of releases due to hypothetical fire / impact scenarios during the operational (and transport) phase further understanding would be beneficial.
It can be desirable to increase the utilization of nuclear fuel to higher burn-up for commercial reasons. The main consequence of higher burn-up is to increase the fission-product radionuclide inventory of spent fuel whilst modifying its physical structure such that porosity and volatile fission-product segregation to grain-boundaries is increased.

EC FIRST Nuclides project covered 12 different types of high burn-up LWR SNF:
• In PWR, mainly UO_2 samples with burn-up between 50 and 70 $GWd.t^{-1}$
• In BWR, mainly UO_2 samples with burn-up between 45 and 59 $GWd.t^{-1}$
MOX spent nuclear fuels were initially identified in the scope of the project, but only one MOX sample had been studied during the project. The project focused on IRF measurement in order to establish correlations between the experimental FGR and the IRF of non-gaseous fission products, in particular for ^{129}I, ^{79}Se and ^{135}Cs.
The main conclusion of FIRST Nuclides is that Future R&D should focus on MOx spent nuclear fuel and doped (Al/Cr/Gd) spent nuclear fuel in order to precise the influence of dopants on IRF.
EC DISCO project aims to assess the influence of geochemistry on spent nuclear fuel dissolution after container failure. It is focused on doped spent nuclear fuel and MOx.
EC Projects: SFS, MICADO, FIRST Nuclides, DISCO</td><td colspan="3">Research Needs/Driver
It would be beneficial to consolidate existing understanding of spent-fuel release processes in the long-term post closure, identify any existing knowledge gaps and develop improved understanding of the behaviour of spent fuel in fire and impact accident scenarios.</td></tr>
<tr><td colspan="3">Research Objectives
• To develop an improved mechanistic understanding of the release of fission products from the different types of spent nuclear fuels to better predict the radionuclide source term in post-closure safety studies.

• To develop understanding of the behaviour of spent fuel contained in waste packages in a range of fire and impact scenarios.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.1.10 Spent Fuel Fissile Content</th></tr>
<tr><td colspan="4" rowspan="2">Background
Characterisation of spent nuclear fuel is required for safe and secure storage and disposal. The quantification of fissile material – primarily ^{239}Pu and ^{235}U (and ^{233}U for thorium fuel cycles) is necessary to address safeguarding and criticality controls. Several methods and techniques exist to characterize the fissile content of spent fuels. The methods allow the determination of the burnup, the total fissile content, the original enrichment of the spent fuel element as well as of the type of fuel. There exist several non-destructive assay systems in use today which primarily measure indirect signatures from spent fuel.</td><td colspan="2">Research Needs/Driver
Quantification of fissile content of spent fuels.</td></tr>
<tr><td colspan="2">Research Objectives
Improved understanding of the characteristics and behaviour of spent fuel.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

1.2 Waste Package and Storage Consequences

A waste package (known also as a ‘final wasteform’) is defined as a unit of conditioned waste ready for the emplacement in a repository; it consists of conditioned waste put in a disposal container and, in some cases, in an overpack.

The waste package is a primary and principal element of the engineered barrier system used to ensure operational and long-term safety throughout the waste management process, starting with its generation (waste conditioning), through transport and storage, until the waste is emplaced in a disposal facility. It should provide containment for a certain period of time, defined in the safety case of a disposal facility.

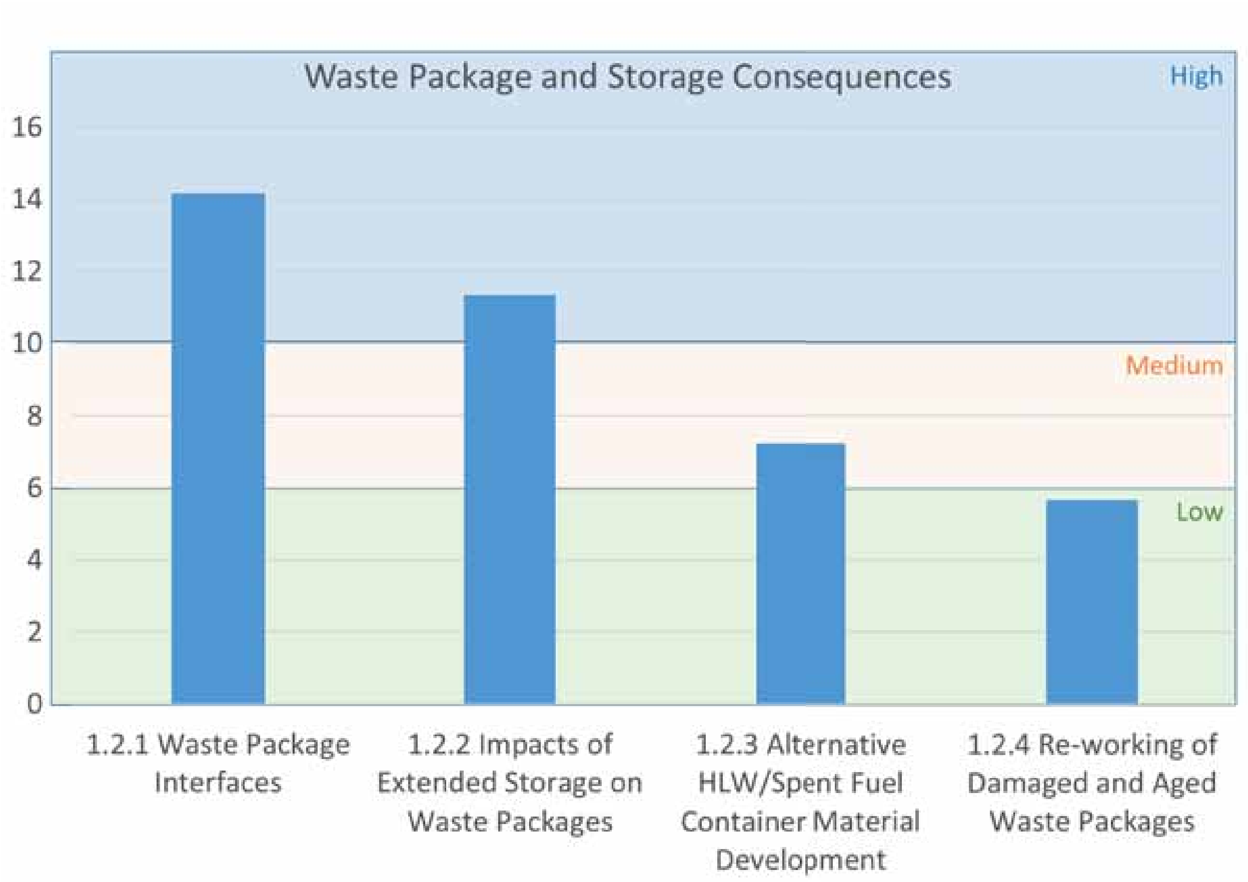
The spectrum of processes and interactions to be considered in the waste package performance assessment is rather broad and covers waste-container, container - Engineered Barrier System elements, and waste package-host rock mutual interferences, as well as their cumulative effects. When regarding the long-term safety, feasible and well-instrumented integral experiments and associated models may provide for more realistic understanding of near-field system evolution, as well as uncertainty analyses of the long-term waste package evolution.

Radioactive waste may be stored for a considerable period of time prior to disposal. Interim storage of waste can cover a timespan of several decades up to a century or more. Unexpected delays in geological disposal programmes may extend storage periods beyond what was originally anticipated in the national programme. Degradation of the wasteforms and waste packages during these relatively long or extended timespans may have an impact on the safety of the storage facility, as well as on the operational and post-closure safety of the geological disposal facility. This issue is therefore of concern for the evaluation of safety of both the short-term and long-term management of radioactive waste.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The level of common interest for the sub-domains are shown in Figure 6 below.

1.2.1 Waste Package Interfaces;
1.2.2 Impacts of Extended Storage on Waste Packages;
1.2.3 Alternative HLW/Spent Fuel Container Material Development;
1.2.4 Re-working of Damaged and Aged Waste Packages.

Figure 6: Level of Common Interest for Waste Package and Storage Consequences Sub-Domains.



<table>
<tr><th colspan="6">1.2.1 Waste Package Interfaces</th></tr>
<tr><td colspan="2" rowspan="2">Background
Understanding of potential interactions between waste packages (that include the waste form and any container(s) and internal barriers) and other EBS components in the hydrogeochemical conditions of a host geological environment provides an insight into the assessment of the long-term safety of a disposal system. Further understanding of the micro-scale evolution of interfaces between waste packages and associated barriers would be beneficial.</td><td colspan="4">Research Needs/Driver
Understanding the interactions occurring at interfaces between waste packages and different barriers in the disposal facility will enhance confidence in the whole EBS and the safety case.</td></tr>
<tr><td colspan="4">Research Objectives
Assessment of 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.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.2.2 Impacts of Extended Storage on Waste Packages</th></tr>
<tr><td colspan="3" rowspan="2">Background
Geological repository development spans a long time period, in some Member States including an extended period of operations and reversibility. Heat generating HLW/SF must also be cooled for a period of time (decades) prior to disposal. These significant storage durations could have an impact on the transport, operational and post-closure safety, as some characteristics of the spent fuel and of the cask may alter over time. In some cases, the ageing of the casks could mean that the cask needs replacing. Furthermore, the investigation of the sealing system of casks and sealing ring materials in terms of their ageing, considering environmental influences as well as thermal and mechanical loads, is of particular importance.
Monitoring of the state of all waste packages (including those for ILW) and of the wasteforms in storage conditions may also be required.</td><td colspan="3">Research Needs/Driver
Identification, characterisation and management of uncertainties related to performance of the final waste package (including the waste form) during prolonged storage (ageing, confinement integrity, handling constraints, wasteform performance) requires further consideration.</td></tr>
<tr><td colspan="3">Research Objectives
To understand the performance of the final waste package (including the waste form) during prolonged storage prior to its transport and disposal.
The assessment of fuel cladding structural integrity and ageing effects on specific materials of dry casks for spent fuel storage may require further R&D work, e.g. experimental studies, measuring techniques, modelling and numerical simulations.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.2.3 Alternative HLW / Spent-Fuel Container Material Development</th></tr>
<tr><td colspan="3" rowspan="2">Background
Currently, either combined copper / cast iron or carbon steel are considered for container materials for HLW/SF; stainless steel, ductile cast iron and concrete are typically considered for container materials for ILW disposal. With new waste streams (advanced fuel cycles) and new host rock systems, alternative container materials for HLW/SF may be considered.
Alternative container material may offer the following advantages:
• To reduce hydrogen production resulting from corrosion of the overpack in anoxic conditions (risk: gas pressure); and
• To increase the robustness of demonstrating long-term material performance.</td><td colspan="3">Research Needs/Driver
To investigate alternative materials to optimise container/overpack design for HLW/SF, whilst maintaining the required level of operational and long-term safety.</td></tr>
<tr><td colspan="3">Research Objectives
To investigate alternative container materials or coatings, suitable for fulfilling container safety functions in current disposal systems.
To identify potential alternative materials for packaging novel wasteforms.
To specify alternative container material functions in particular disposal systems and to appropriately characterise their relevant properties, e.g. ceramics.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.2.4 Re-working of Damaged and Aged Waste Packages</th></tr>
<tr><td colspan="2" rowspan="2">Background
During handling, transport, and prolonged storage waste packages might be damaged by incidents or due to the degradation of container materials (corrosion). Waste can be stored for a significant period of time in storage facilities or in the disposal facility prior to its final emplacement. These significant storage durations could have an impact on transport, operational safety and the post-closure safety as some characteristics of the wasteform and of the waste packages may alter over time.
Such packages must be re-packed or even reworked prior to their disposal to minimize the potential for violation of safety requirements. The identification of criteria to determine whether defected wasteforms need to be re-worked and of what type of re-working is necessary is therefore of interest.</td><td colspan="4">Research Needs/Driver
This topic is aims to:
Exchange information on the management of damaged waste packages enabling the transfer of good practice from more advanced Member State programmes to less advanced programmes;
Determine the circumstances in which re-working of a wasteform (e.g. providing an additional overpack or applying a new treatment to the waste) has to be performed and what type of re-working is appropriate.
This subdomain is considered to be relevant to ILW, HLW and spent fuel.</td></tr>
<tr><td colspan="4">Research Objectives
To share good practices with respect to minimising radiological consequences and addressing waste acceptance criteria in the event that packages have become damaged prior to transfer to a geological disposal facility.

To identify and share best practices on the identification and use of criteria to determine whether re-processing of aged waste is necessary and of an appropriate reprocessing method.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

1.3 Near-field and Engineered Barrier System

The choice of buffer and backfilling materials is partly dependent on the chosen disposal concept. Buffer and backfilling have important safety functions in some disposal concepts, depending on the disposal concept under consideration and the geological environment of the site. Cementitious materials are extensively planned to be used as disposal structures (buffer, plugs). Further understanding of the thermal, hydro and mechanical (THM) behaviour of concrete materials, taking into account their chemical degradation, would be beneficial. This is especially the case for low pH cements. Bentonite is intended for use as a buffer around high-level waste canisters and also as a seal. Clay-based materials (i.e. excavated rocks with additives) may also be used to backfill galleries in the disposal facility. Despite on-going studies, the whole supply chain for bentonite buffer materials needs more RD&D work.

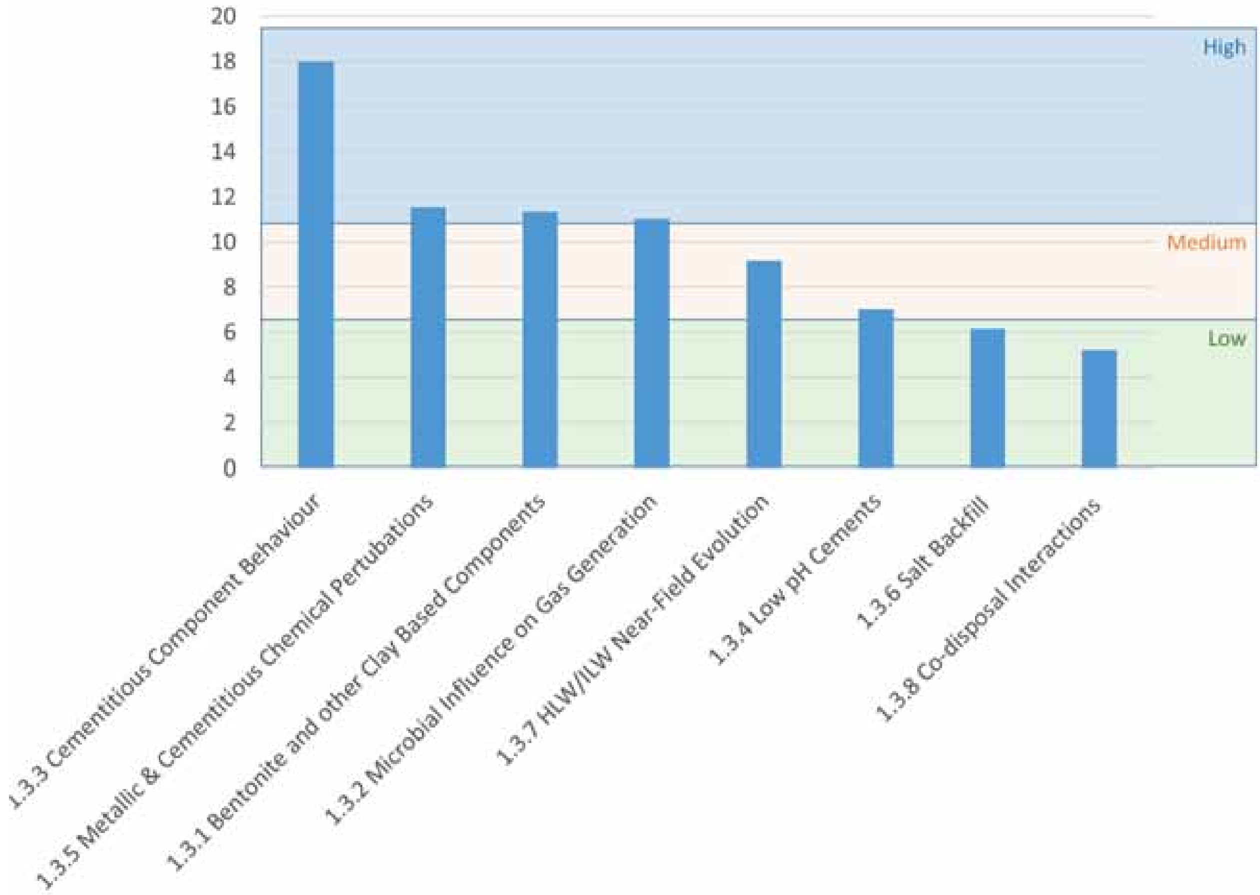
In evaporite environments (e.g. halite) RD&D may also be required in order to maintain the integrity of the near field (and far field) via appropriate engineering of backfill regimes and seals.

The coupled mechanical/chemical evolutions at the interfaces between the different materials (glass/iron/clay, cement/bentonite, cement/metal, bentonite/metal) and between these materials and the host rock (iron/clay interactions, alkaline perturbation) are a topic of strong interest to assess the global evolution of the near field. The difference between relatively ‘short-term’ interactions (e.g. resaturation) versus ‘long-term’ interactions (e.g. development of gas pressure, cement degradation etc.) occurring at these interfaces is 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).

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The level of common interest for the sub-domains are shown in Figure 7 below.

1.3.1 Bentonite and Other Clay Based Components;
1.3.2 Microbial Influence on Gas Generation;
1.3.3 Cementitious Component Behaviour;
1.3.4 Low pH Cements;
1.3.5 Metallic & Cementitious Chemical Perturbations;
1.3.6 Salt Backfill;
1.3.7 HLW/ILW Near-field Evolution;
1.3.8 Co-disposal Interactions.

Figure 7: Level of Common Interest for Near-Field and Engineered Barrier Systems Sub-Domains.



1.3.1 Bentonite and other Clay Based Components					
Background 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 150°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 leading to serpentinization). Consequently, such changes can lead to evolution of transport and chemical properties, or even in mechanical behaviour changes. ***EC Projects: BENIPA, BELBaR***			**Research Needs/Driver** Further studies of bentonite and clay based materials to assess the role of: variations of properties arising from barrier installation, hydration history, elevated temperatures and chemical influences on long-term evolution behaviour. **Research Objectives** To characterise bentonite evolution under specific conditions to provide data on hydro-mechanical, thermal and chemical behaviour. To provide guidance on the use of clay materials depending on their origin or mineralogy. To enhance understanding of post-closure safety considerations by extensive characterisation of the different phenomena, e.g. thermal evolution or interactions with metallic or cementitious components (alkaline perturbation, ion-exchanger modification) or with the host rock.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

1.3.2 Microbial Influence on Gas Generation

Background	**Research Needs/Driver**
After O_2 disappearance in the near field, anoxic corrosion of steel is expected to produce hydrogen gas. Simultaneously, microbes may reduce oxidized species like sulfate and produce other gases like H_2S, which may react with metals to form sulphides. The formation of methane depends on the presence, transport and reactivity of sulfate. In general, the influence of microbial processes is addressed via bounding assumptions in disposal facility safety cases. ***EC Projects: MIND***	Where a safety case requirement is identified for improved mechanistic understanding, rather than bounding assumptions, it may be necessary to: • Quantify kinetics of microbial catalysis of both gas consumption or gas production reactions, and the competition between them. • Improve the topological description of rock surfaces interacting with gases. **Research Objectives** To produce relevant chemical and microbial data from in situ experiments in realistic / genuine near-field conditions in order to better quantify the consequence of microbial processes.

Implementation Driven	
Transfer of Knowledge to LAPs	

Level of Common Interest

High		Medium		Low	
	✓				

1.3.3 Cementitious Component Behaviour

Background	**Research Needs/Driver**
Cementitious materials are planned to be used as waste packages and confinement matrices, as well as disposal structures. Their physical behaviour, especially during the operational phase and 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 concrete components these studies have been extended to a longer time-period, considering various operating conditions. Early age behaviour (coupled chemical and mechanical behaviour) of concrete is important to determine "initial properties" and to be able to model the long-term behaviour of a structure. ***EC Projects: CEBAMA***	It is important to increase confidence in simulations by reducing uncertainties in input data and understanding of key processes, taking into account specific conditions for waste disposal (temperature, radiation, chemical composition, etc.). **Research Objectives** To quantify, according to various cement / concrete types, the evolution of the chemical and physical properties (of sound and degraded materials) to improve long-term modelling and assessments. To reduce the uncertainties of the physical evolution during the THM-transients involving the wastes and the geological medium. Priorities should be given to: • Hydromechanical (shrinkage, creep) behaviour of concrete (including the effect of temperature and relative humidity variations). • Passive and active corrosion and damaging consequences (in oxic and anoxic conditions). To support the design process and dimensioning, including raw material choices and their impact on the initial properties. To explore the effects of waste degradation (resulting in sulfates, ammonium salts, organic acids, etc.). on cementitious component evolution.

Implementation Driven	✓
Transfer of Knowledge to LAPs	✓

Level of Common Interest

High		Medium		Low	
	✓				

<table>
<tr><th colspan="6">1.3.4 Low pH Cements</th></tr>
<tr><td colspan="2" rowspan="2">Background
Low hydration heat/low pH cements are recent materials developed in the nuclear waste disposal context which have been investigated by some Waste Management operators, although no background exists in the civil engineering context. Most investigations deal with formulation vs initial expectations/requirements. The main requirements are on short-term chemical evolution to achieve the “low pH” property as fast as possible. This chemical property is important so as not to lead to long-term chemical interactions with clay materials which can lead to degraded safety functions (swelling clay in plugs and seals and/or clay host rock). There is also little information on the corrosion of steel rebar in low pH cement environments.
EC Projects: CEBAMA</td><td colspan="4">Research Needs/Driver
In order to support safety case and design development it is necessary to consolidate and expand on existing understanding of low pH, including their composition, impact of radionuclide migration and practical implementation.</td></tr>
<tr><td colspan="4">Research Objectives
To consolidate existing knowledge on low pH cements, including:
• Reviewing the composition of low pH cements and their potential for retarding particular radionuclide migration.
• Determining suitable methodology for measuring the pH of cements.
• Providing understanding of the reinforcement corrosion process in low pH concrete if reinforced concrete is used.
Providing understanding of low-pH cements evolution (pH, mineralogy) under high temperatures (up to 90 °C), at interfaces with carbon steel, and taking into account groundwater chemistry.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
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<table>
<tr><th colspan="6">1.3.5 Metallic & Cementitious Chemical Perturbations</th></tr>
<tr><td colspan="2" rowspan="2">Background
The host rock in the near field of the disposal system may be influenced by the degradation of metallic and cementitious materials. These materials may be used as structural materials or waste package components. The characterisation of the phenomena is of interest to support the performance assessment and the safety assessment.</td><td colspan="4">Research Needs/Driver
Development of further understanding of the impacts of different phenomena (i.e. metal corrosion / secondary phase formation and cement alteration) on EBS components and near-field chemical evolution (e.g. alkaline perturbation on host rock) via improved models.</td></tr>
<tr><td colspan="4">Research Objectives
To improve the geochemical models used in near-field modelling through numerical and experimental characterisation of their evolution and identification of the key THMC evolution processes.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
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<table>
<tr><th colspan="6">1.3.6 Salt Backfill</th></tr>
<tr><td colspan="4" rowspan="2">Background
A disposal facility for radioactive waste may be sited in a salt host rock, e.g. the Waste Isolation Pilot Plant (WIPP) in the USA. A crushed salt backfill may be adopted to close disposal areas. The crushed salt backfill isolates the waste containers from any porewater in the rock and would compact and creep and eventually converge with the tunnel walls as the salt host rock creeps and provides further sealing of the waste with a complete barrier of low permeability salt. In thinner salt deposits the backfill will reduce the required extent of creep, mitigating the risk of propagated damage through the salt deposit.
EC Projects: BAMBUS II</td><td colspan="2">Research Needs/Driver
To further understanding about salt backfills.</td></tr>
<tr><td colspan="2">Research Objectives
To understand the long-term behaviour and properties of a salt backfill, including influences of pressure and temperature on behaviour.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">1.3.7 HLW / ILW Near-field Evolution</th></tr>
<tr><td colspan="3" rowspan="2">Background
Various near-field materials (iron, stainless or carbon steel, cementitious or bentonitic grouts, etc.) have been considered for placement between glass-containing canisters and clay host rock. Many complex coupled systems have been studied to date, from laboratory mock-ups to in situ tests, but only simple coupled systems have been deeply investigated and understood (experimentally and by simulation). The presence of reactive solids near the glass significantly increases the number of potential processes: sorption reactions, dissolution / precipitation of new phases, coprecipitation, incorporation of solid phases and solid solution formation, local changes in pH or in solution composition, local porosity clogging changing the transport properties of aqueous species, redox reactions, etc.
It has been shown that transport of reactive species at the micron to millimetre scale is rate controlling in most of the glass-nearfield-materials systems already investigated.
Most of the studies are devoted to the evolution of vitrified waste disposal cells but this sub-domain also addresses the evolution of the near field for intermediate wastes, such as organic waste (polymers, bitumen), metallic waste, etc.</td><td colspan="3">Research Needs/Driver
Nearfield materials are expected to react with:
• HLW / ILW glass, more or less rapidly, depending both on thermodynamics and on the transport of reactive species,
• Organic acids, salts released by wastes.
Performance assessment of such a near-field system relies on the description of the spatial and temporal evolution of transformations affecting the porous media and degrading materials.</td></tr>
<tr><td colspan="3">Research Objectives
To improve 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.).
For vitrified waste, understanding and predicting the behaviour of such complex systems could help improve modelling of the reference case with minimised uncertainties and later, optimize the EBS with a potential gain of orders of magnitude in glass lifetime.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.3.8 Co-disposal Interactions</th></tr>
<tr><td colspan="4" rowspan="2">Background
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 glass, 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. In some national programmes, (co-) disposal of various types of non-heat-generating waste is foreseen for a single geological facility. The main focus for co-disposal R&D is to:
• identify waste types and compositions that can generate plumes problematic for the integrity and retention of other wastes in a facility;
• assess the potential impact on safety; and
propose remedial actions such as introducing a ‘respect distance’ between respective disposal concepts, or changing conditioning of certain waste types in order to avoid the potential for problematic plumes.</td><td colspan="2">Research Needs/Driver
Optimizing the use of geological facilities by enabling disposal of wastes with a variety of compositions and properties.</td></tr>
<tr><td colspan="2">Research Objectives
To identify R&D or knowledge transfer in support of optimization of disposal of wastes of different characteristic composition and properties in a single geological disposal facility.</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

1.4 Gas Generation and Transport

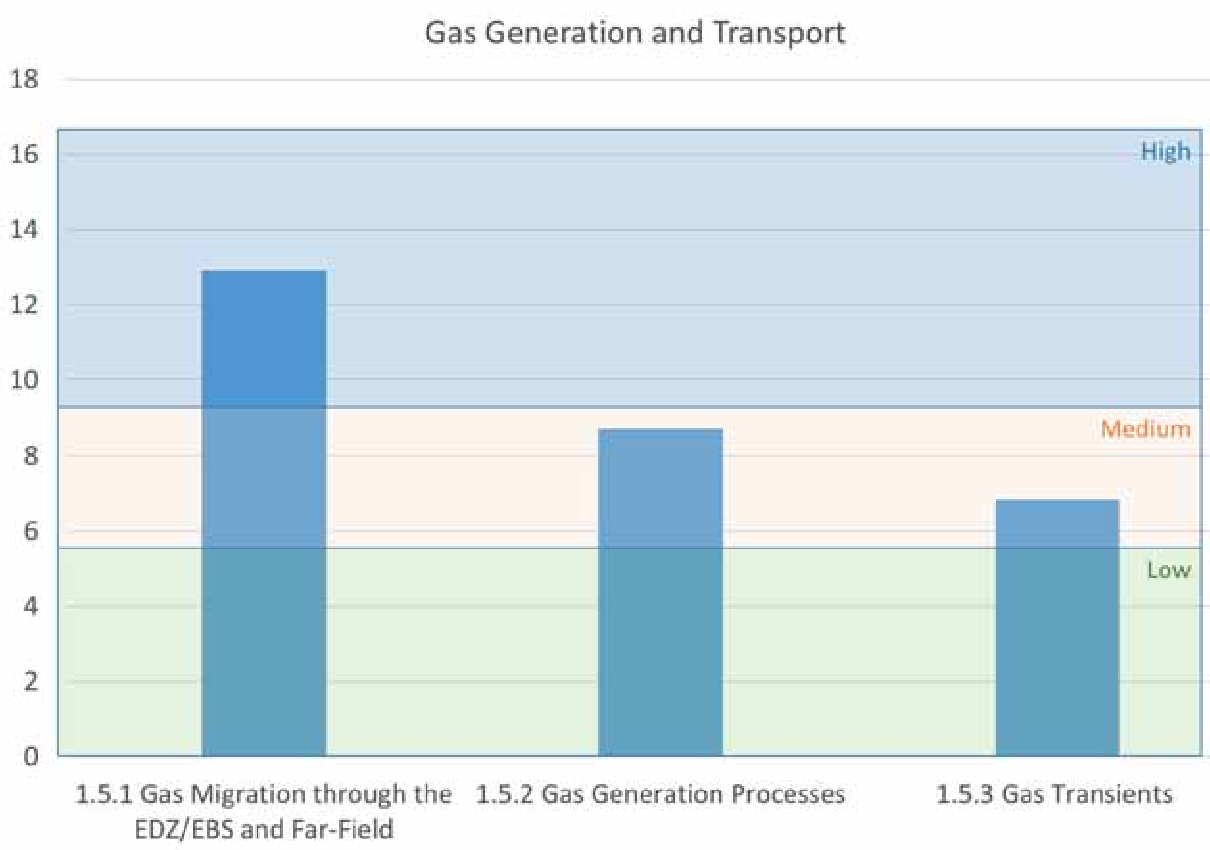
Gases will be generated during transport, operations and after closure of a geological disposal facility. It is necessary to understand the rates of generation of these gases during all phases of a geological disposal facility, their effect on the Engineered Barrier System (EBS) their migration from the EBS after closure (and any potential effects on the host rock) and their effect on solute migration (partial desaturation), in order to demonstrate safety during transport to a geological disposal and throughout subsequent phases of the geological disposal facility.

The properties of the host rock and geosphere control the migration of gas from a facility and thus 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 Opalinus Clay or an evaporite, 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 GDF 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 concepts, the potential for migration of free gas containing gaseous radionuclides to the biosphere is an important issue.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The level of common interest for the sub-domains are shown in Figure 8 below.

1.4.1 Gas Migration though the Excavation Disturbed Zone/EBS and Far-Field;
1.4.2 Gas Generation Processes;
1.4.3 Gas Transients;
1.4.4 Gas Reactivity.

Figure 8: Level of Common Interest for Gas Generation and Transport Sub-Domains.



<table>
<tr><th colspan="6">1.4.1 Gas Migration through the Excavation Disturbed Zone/EBS and Far-Field</th></tr>
<tr><td colspan="2" rowspan="2">Background
In a low permeability host rock bulk gases, if formed in sufficient quantity, would migrate from the EBS as a free gas phase. Migration of gas within the EBS and through the rocks surrounding the GDF will depend on the geological disposal concept and the individual site(s) being considered. The international FORGE (Fate Of Repository Gases) project investigated gas migration issues of relevance to GDF performance assessment.
EC Projects: GASNET, FORGE</td><td colspan="4">Research Needs/Driver
Bulk gas migrating out of waste packages and buffer / backfill, through the Excavation Disturbed Zone (EDZ) may provide an important route for a free gas-phase to migrate into the far field. Gas migration through the EDZ is therefore of importance in clay formations and needs have been identified concerning upscaling from laboratory tests and observations in URLs to the repository level.</td></tr>
<tr><td colspan="4">Research Objectives
To increase understanding of gas migration and reaction in different host rocks, in particular to 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. This may include specific work on carbon-14 migration, understanding gas flow in engineered barrier materials at elevated temperatures, and gas interactions between packages and backfill.
To consider the impact of engineering design on migration from the EBS and migration through the EDZ.
To refine models of gas migration, including the treatment of uncertainty arising from the nature of the geological environment.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

1.4.2 Gas Generation Processes

Background	**Research Needs/Driver**
The formation of gases from processes occurring in many waste packages, e.g. corrosion of metals in the waste or the container, or from the radiolysis of water, is unavoidable. There is a general consensus that the key bulk gas generation processes applicable to a GDF are the corrosion of metals, microbial action on organic materials and radiolysis (organic materials, concrete, salts, etc.). The impact of gases on the safety case is either associated with the production of non-radioactive (bulk) gases or the radiological impacts of (trace) gases containing radionuclides such as tritium, ^{14}C and ^{222}Ra. Both the rate at which gases containing ^{14}C might be produced from the waste (currently investigated by the EC funded CAST Project), and the radiological consequences associated with ^{14}C labelled species migrating to the biosphere, are important considerations. ***EC Projects: CAST***	To increase understanding of the generation and release of radioactive trace gases and bulk gases from wasteforms and waste packages. **Research Objectives** • To identify and resolve any outstanding research, development and demonstration requirements arising from the EC CAST project. • To increase understanding of the generation and release of gases (H_2, CO_2, CH_4, HCl, CO, HF, HCN, etc.) resulting from radiolysis of polymers, including the influence of temperature. • To increase understanding of the generation and release of hydrogen resulting from corrosion, e.g. reactive metals (aluminium, magnesium), reaction of beryllium in alkaline solutions, influence of organic acids and complexing species, etc. To further understand bulk gas generation from ILW, and gas generation from HLW and spent fuel, and potential impacts on the disposal system. Specific work may be focused on the potential for formation of flammable gas mixtures for gases such as hydrogen, the radiotoxicity hazard from the generation of radioactive gases, and the possible hazard from the generation of chemotoxic or asphyxiant gases.

Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.4.3 Gas Transients

Background	**Research Needs/Driver**
Water (including solutes) and gas transfer during the resaturation phase is complex due to all the coupling between hydraulic and other processes. The coupling with thermal ones 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 a 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.	Increase the degree of representativeness of two-phase flow models which may be used at disposal scale by increasing the level of coupling with mechanics especially. **Research Objectives** Develop and implement in two-phase flow numerical codes new models able to increase the representation of numerical evaluations at disposal scale.

Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.4.4 Gas Reactivity					
Background Gases generated in a repository may interact in different ways with the EBS and host rock through which they migrate. Beside more physical processes such as sorption and dissolution, gases may undergo abiotic chemical and microbially mediated reactions in the subsurface environment. For instance, H2 is a potent reducing agent which could contribute to maintain or to restore strongly reducing conditions. However, the reaction of H2 with clay components and iron-containing materials could also affect the stability of clay minerals and the corrosion of metallic barriers. H2 is also one of the most energetic substrates for microbial life in deep subsurface environments and can fuel bacterial activity.			**Research Needs/Driver** The potential implications for safety of gas reactivity in a GDF are manifold as these interactions may alter the physical and chemical characteristics of the migrating gas as well as of different phases of the media where they take place. **Research Objectives** To increase understanding of gas reactivity in EBS and host rocks in repository conditions and its potential impacts on geochemistry, safety-relevant processes and radionuclide migration.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

1.5 Radionuclide and Chemical Species Migration

After isolation of radioactive waste in deep geological formations, only by slow migration in groundwater and to a very small degree by a gaseous pathway, can radionuclides enter the biosphere, a process which typically takes many hundreds of thousands of years. The rate of radionuclide migration depends not only on the distance of the repository 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; anions interact only slightly with typical negatively-charged surfaces, but in porous media ion-exclusion may reduce the speed of migration. For cations, retention increases with cation charge; monovalent alkali ions are much less retained than tetravalent actinides. The geochemical environment strongly influences radionuclide migration; e.g. in reducing geochemical environments actinides are almost immobile. Radionuclide migration is also influenced by organic matter, micro-organisms and gases present along the transport path.

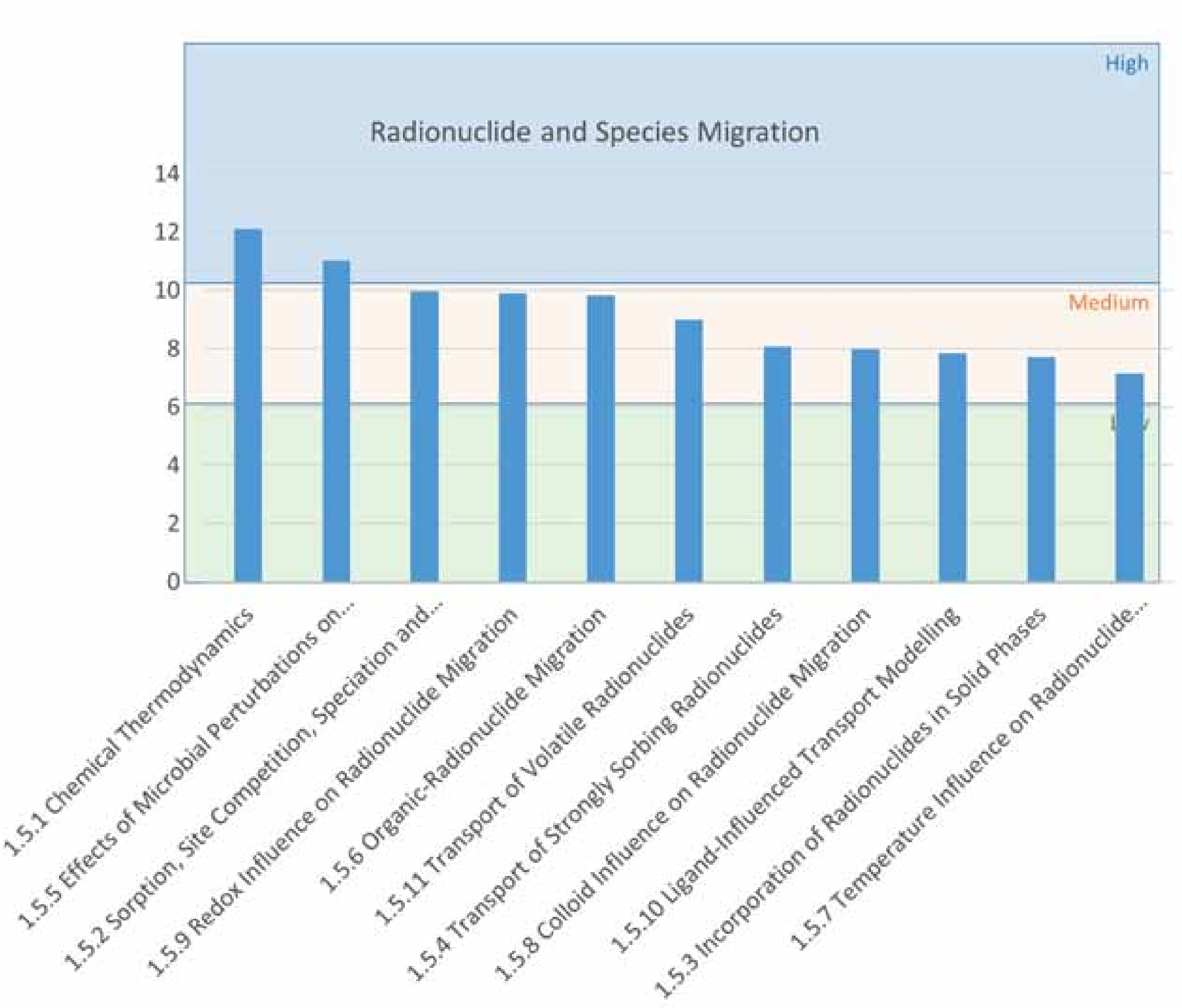
There has been research on the various topics of radionuclide migration for more than 30 years, often funded by the European Commission. This has included both detailed mechanistic and applied studies. The present programme focuses on remaining uncertainties.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 9 below.

1.5.1 Chemical Thermodynamics;
1.5.2 Sorption, Site Competition, Speciation and Transport;
1.5.3 Incorporation of Radionuclides in Solid Phases;
1.5.4 Transport of Strongly Sorbing Radionuclides;
1.5.5 Effects of Microbial Perturbations on Radionuclide Migration;
1.5.6 Organic-Radionuclide Migration;
1.5.7 Temperature Influence on Radionuclide Migration;
1.5.8 Colloid Influence on Radionuclide Migration;
1.5.9 Redox Influence on Radionuclide Migration;

1.5.10 Ligand-Influenced Transport Modelling;
1.5.11 Transport of Volatile Radionuclides.

Figure 9: Level of Common Interest for Radionuclide and Chemical Species Migration Sub-Domains.



<table>
<tr><th colspan="3">1.5.1 Chemical Thermodynamics</th></tr>
<tr><td rowspan="2">Background
Assessment of the long-term performance of the disposal system relies on the understanding and quantification of the thermodynamic driving forces for degradation of waste matrices and mobilization and retention of radionuclides. High quality thermodynamic data are generally usable beyond a given disposal configuration and if one is able to base long-term performance assessments largely on such data, one can create high credibility and confidence. This can be linked to the NEA-thermodynamic database (TDB) approach which provides high quality assurance and clear identification of priorities.</td><td colspan="2">Research Needs/Driver
To further develop transparent and quality assured thermodynamic databases for use in performance assessments.</td></tr>
<tr><td colspan="2">Research Objectives
To determine 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.</td></tr>
<tr><td colspan="2">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="2">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="3">Level of Common Interest</td></tr>
</table>

High	✓	Medium		Low	

<table>
<tr><th colspan="2">1.5.2 Sorption, Site Competition, Speciation & Transport</th></tr>
<tr><td rowspan="2">Background
Radionuclide transport in groundwater or in pore water of porous media is the principal process challenging the long-term isolation of radionuclides in deep geological formations. The rate of transport is reduced strongly (1) by retention of radionuclides on sorption sites on the surface of minerals and engineered barrier materials and their alteration products and, (2) in nano-porous media like clays and also by anion exclusion. The extent of sorption depends on the radionuclide, its speciation in solution, the geochemical boundary conditions and on the nature of the solid phases. Competition between the main elements for sorption sites may reduce the number of sites available for radionuclides.
EC Projects: CatClay</td><td>Research Needs/Driver
To further characterize sorption mechanisms (surface complexation) and coupled chemistry/transport models for various media.</td></tr>
<tr><td>Research Objectives
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. This will elucidate the influence of 3D-rock anisotropy/heterogeneity on radionuclide migration.
To develop multi-species reactive transport models for cement-based materials with a level of performance equivalent to those previously developed in clay-rich systems (EC CatClay project). This could be done based on an experimental and numerical up-scaling strategy.
To further develop models able to take into account the behaviour of radionuclides in complex systems (including the effects of organic and inorganic ligands, redox transitions, etc).</td></tr>
<tr><td>Implementation Driven</td><td>✓</td></tr>
<tr><td>Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="2">Level of Common Interest</td></tr>
</table>

High		Medium	✓	Low	

<table>
<tr><th colspan="2">1.5.3 Incorporation of Radionuclides in Solid Phases</th></tr>
<tr><td rowspan="2">Background
In contrast to radionuclide retention by sorption, the incorporation of radionuclides in solid phases in waste matrices and along migration paths, provides a different and very powerful retention mechanism. This is because incorporated radionuclides are not necessarily released upon contact of the solid with groundwater. This leads to partially irreversible entrapment as a strong safety factor for the repository system. Important solids in this context are spent fuel and glass, and their alteration products, as well as slowly forming and dissolving mineral phases in the far-field.</td><td>Research Needs/Driver
To quantify long term entrapment in key solid phases for key radionuclides (e.g. ^{14}C and U as carbonates and ^{79}Se in sulphur-bearing phases) and characterize the governing entrapment mechanism.</td></tr>
<tr><td>Research Objectives
Mechanisms for irreversible entrapment need to be characterized and modelled. Typical mechanisms are by diffusion or recrystallization by a dissolution/precipitation process. Suitable emphasis should be placed on understanding both thermodynamics and kinetics.
Experiments to characterise the reversibility of incorporation reactions, informing reactive transport models.
The impact of changes in reactant concentrations by host material dissolution and geochemical boundary conditions should be appropriately represented in geochemical codes.</td></tr>
<tr><td>Implementation Driven</td><td>✓</td></tr>
<tr><td>Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="2">Level of Common Interest</td></tr>
</table>

High		Medium	✓	Low	

1.5.4 Transport of Strongly Sorbing Radionuclides

Background

Strongly sorbing radionuclides only move a very short distance over geological time periods. Typical strongly sorbing nuclides are tri-and tetravalent actinides and tetravalent technetium. The actual migration distance is difficult to assess and requires sophisticated solid-state analytical techniques. Migration distances can increase by complexation with organic ligands originating from the waste, even though retention remains very strong. In porous or fractured rock, faster transport is sometimes observed. Detailed processes are dealt with in existing projects like EC SKIN. Other projects, like CatClay have finished, but future work is still necessary.

EC Projects: SKIN, CatClay

Research Needs/Driver

Even if strongly sorbing radionuclides in a repository constitute only a small risk to the environment, more understanding is desirable to increase confidence, exploring for instance the chemical degradation of the cement-based materials, the presence of organic molecules, saline groundwaters, etc.).

Research Objectives

To determine how to better:

- Represent heterogeneous media (cement-based materials, clay-rock, crystalline rocks, bentonite, corrosion products, etc).
- Simulate anoxic environmental conditions.
- Predict the transport of strongly sorbing nuclides.
- Characterize the retention of redox sensitive radionuclides or toxic elements.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.5.5 Effects of Microbial Perturbations on Radionuclide Migration

Background

Microbes and fungal activity can influence radionuclide migration by biosorption, metabolic processes, formation of biofilms, etc. By release of organic molecules (siderophores), microbes can produce soluble radionuclide complexes. Microbial activity can also influence the chemical environment and in particular the redox state of radionuclides. Nitrates may influence the fate of microbes. In the absence of microorganisms, the transformation of sulfate to sulphide is, e.g. extremely slow, while it is fast in presence of sulfate-reducing bacteria. There is a lot of sulfate in typical repository environments and sulphide formation may strongly influence the geochemical near-field environment. The geochemical environment and the presence of gases (H_2, others) will strongly influence microbial populations and activities. Based on previous and ongoing work (e.g. EC MIND) the role of microbes is typically addressed in implementers' safety cases by bounding assumptions.

EC Projects: MIND

Research Needs/Driver

Bounding conditions for predictions of microbial activity may be required for performance assessments. Quantitative information on microbe populations, energy and carbon source availability (site specific, waste specific) would be beneficial in this context.

Research Objectives

The impact of microbes on the chemical environment needs to be considered as a function of time to understand and quantify the fate and impact of microbial activity on radionuclide migration.

Assessment of the influence of gas on geochemistry and microbial activity in the near-field, considering void spaces, release of hydrogen, organic ligands, nitrates, sulphides, and methane to assess the impact on barrier performance and radionuclide migration.

It would be beneficial to develop methods to upscale from phenomenological descriptions to mechanistic models.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

1.5.6 Organic-Radionuclide Migration					
Background It is likely that a variety of organic substances will be part of any disposal concept, either from the waste inventory, or as superplasticiser for concrete structures, or from pre-existing organic matter in the geological formation. It is possible to consider a variety of substances, likely to be present and known for stability, mobility and radionuclide complexation in laboratory /in situ transport experiments and models. An example of a very organic-rich waste type is bitumized waste. Organic matter can influence radionuclide migration by creating soluble or colloidal complexes with radionuclides, which would otherwise be insoluble, or by blocking sorption sites. Hyperalkaline water and entrained admixture compounds arising from cementitious systems may increase the mobility of organic matter. In clay rock only small organic molecules can be transported, larger ones are filtered in clay pores.	**Research Needs/Driver** Further research is required to enhance understanding of the role of organics (either naturally occurring or as introduced in the wastes) and their influence on radionuclide migration. **Research Objectives** Studies may include: (i) the nature of the organic molecules generated by the organic waste or admixture degradation, (ii) their stability with time, (iii) their effects on radionuclide migration (speciation, solubility, retention, diffusion as a complex organic/radionuclide), (iv) the effect of cocktail of organic molecules, (v) the nature and release rate of organic compounds resulting from polymers radiolysis and hydrolysis, and (vi) implementation in a reactive transfer model.				
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.5.7 Temperature Influence on Radionuclide Migration					
Background Elevated temperature may change the migration behaviour of radionuclides by changing sorption constants, by changing diffusion coefficients in porous media or by influencing the stability of organic matter or of minerals. There are only a few studies on the effect of temperature on radionuclide migration and a more robust understanding could be provided by confirmatory studies of sorption constants at a few selected temperatures.	**Research Needs/Driver** To support concept optimisation by studying temperature effects on some key radionuclides in a realistic near field environment and incorporating this understanding in a geochemical model. **Research Objectives** To develop an improved understanding of sorption constants for radionuclides (K_d or surface complexation constants) as a function of temperature. To develop a better understanding of groundwater composition as a function of temperature. To consider the effect of temperature on potential transformations of solid phases, radionuclide speciation and any associated impact on solubility.				
Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

<table>
<tr><th colspan="6">1.5.8 Colloid Influence on Radionuclide Migration</th></tr>
<tr><td colspan="3">Background
Colloids can be organic or inorganic. Their size is typically smaller than 0.5 µm so that they do not settle during groundwater transport. In a repository, colloids may pre-exist in the groundwater system, or may be generated by interaction of groundwater with repository components. Important examples are colloids formed by interaction of glacial melt water with bentonites. Clay rock and swelling clay backfills are filters against colloid transport and this is well documented. If colloids are filtered they do not contribute to radionuclide migration. If colloids are transportable, colloidal transport is particularly important for radionuclide migration, especially for radionuclides which are sparingly soluble and strongly sorbed.
EC Projects: BELBAR</td><td colspan="3">Research Needs/Driver
To increase confidence in post-closure safety cases by improved understanding of the role of colloid generation and transport for different host rocks and disposal.

Research Objectives
To conduct experiments and model development for colloid generation and transport; colloids may arise from bentonite erosion, organic species degradation, cement material degradation, etc).
To investigate transport parameters for inorganic colloids or radionuclide/organic complexes.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">1.5.9 Redox influence on Radionuclide Migration</th></tr>
<tr><td colspan="2">Background
Redox conditions influence radionuclide migration. Most repository concepts are based on a reducing environment. Under these conditions actinides and technetium are largely in a tetravalent redox state. Much higher solubility would be expected under oxidizing conditions. This is the principal reason that actinides contribute only a small amount to overall risk from a geological disposal facility. Redox conditions can however be influenced by waste compounds introduced to the near field (e.g. nitrates, organic matter) and in this context micro-organisms can play an important role. The EC ReCosy project dealt mainly with bulk redox conditions.
EC Projects: ReCosy</td><td colspan="4">Research Needs/Driver
Post-closure safety case uncertainty would be reduced by improved understanding of:
(i) The temporal and spatial evolution of redox conditions in engineered barrier systems (for instance around steel reinforcement in concrete).
(ii) The effect of redox perturbations (e.g. arising from the presence of nitrates / organic matter) able to modify the expected oxidation states (and mobility) of radionuclides.
(iii) The role of kinetics of radionuclide reduction/oxidation.

Research Objectives
To develop geochemical models for identifying, simulating and spatial monitoring of local and global anoxic conditions and/or redox transitions, including the associated modelling and transfer to realistic conditions. A small number of smaller in-situ experiments may be beneficial, and the duration of the oxic phase after repository closure may also be investigated.
To characterise the mobility of radionuclides under perfectly well controlled redox conditions and complex conditions (pCO_2, pH, nitrate, etc.) for clay-rock and cement-based materials. Anoxic conditions in experiments cannot replicate negative Eh; suitable anoxic conditions must be generated by the application of electrochemical or chemical reducing agents.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

1.5.10 Ligand-Influenced Transport Modelling

Background	Research Needs/Driver
Some long-lived non-heat generating waste may contain large quantities of salts or organic matter. The release of salts may contribute to enhanced salinity in local environments which may influence radionuclide migration. In particular, sorption on solids can be much lower than in the absence of salinity. Released organic matter may lead to the formation of soluble complexes with organic ligands of otherwise sparingly soluble radionuclides. The migration of the organic ligands away from the waste constitutes a possible mechanism for the mobilization of otherwise sparingly soluble radionuclides by this ligand front.	Post-closure safety case uncertainty would be reduced by improved understanding of the impact of organic ligands on radionuclide solubility enhancement. **Research Objectives** To develop and assess the implications of a realistic organic matter spectrum that may be released from certain waste types, including the development of complexation constants of key nuclides (e.g. actinides). To develop models of actinide migration (in near and far field) with more realistic and transportable organic matter spectra in the waste.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.5.11 Transport of Volatile Radionuclides

Background	Research Needs/Driver
Some radionuclides can exist in a volatile state, e.g. ^{3}H or ^{14}C. Both can be in an organic or inorganic form. During the operational phase, radionuclides may be released to the ventilation system. A source term is not yet known, but the quantities which are volatile will be rather low. The release of volatiles from irradiated graphite has been studied in the context of the Carbowaste and CAST programmes. ***EC Projects: Carbowaste, CAST***	Although it is possible to make bounding estimates of the quantities of potentially volatile radionuclides in the waste, further quantification and determination of the release and transport mechanisms for both organic and inorganic fractions would be beneficial. Improved understanding of the influence of disposal system parameters (e.g. temperature, pressure, groundwater composition) and design on gas migration (including possible two-phase flow) in strongly heterogeneous near-field systems would also be beneficial. **Research Objectives** 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. To develop understanding of the capacity of host rocks and cement-based materials to interact with mainly ^{3}H and ^{14}C.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.6 Geosphere

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 contributes to containment by delaying the movement of any potential small amounts of long-lived radionuclides that are released from the facility, 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 at more northerly latitudes. Processes generally occur more slowly at depth; therefore reasonable predictions of long-term behaviour and evolution can be made.

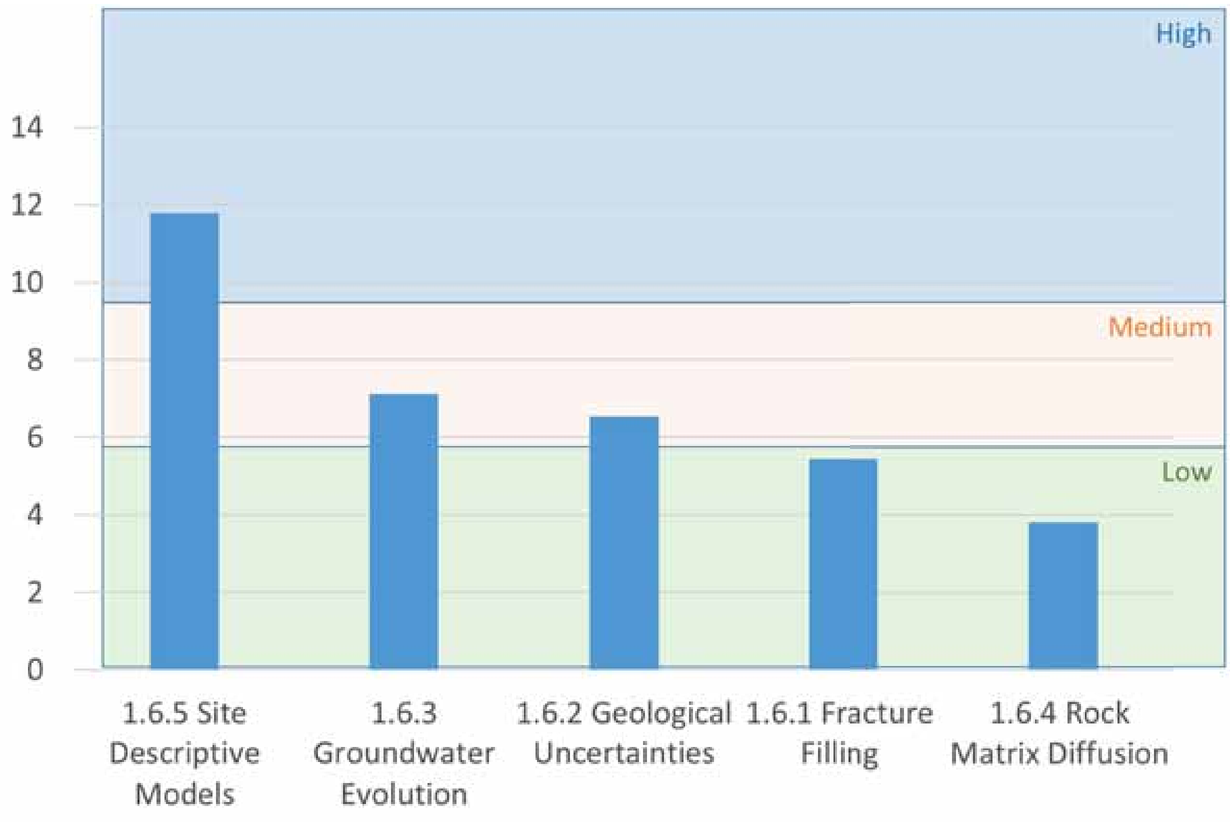
Groundwater movement through the environment will depend largely on the hydrogeological properties of the host rocks and cover rocks. It is necessary to develop an understanding of the hydrogeology at a site in sufficient detail to judge the suitability of the site and to meet the needs of safety assessments and engineering design.

Site characterisation comprises detailed surface and subsurface investigations and is required to acquire and interpret information on geological, hydrogeological and environmental and socio-economic conditions at a site, throughout all stages of the development and implementation of a geological disposal facility.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The level of common interest for the sub-domains are shown in Figure 10 below.

- 1.6.1 Fracture Filling;
- 1.6.2 Geological Uncertainties;
- 1.6.3 Groundwater Evolution;
- 1.6.4 Rock-matrix Diffusion;
- 1.6.5 Site Descriptive Models.

Figure 20: Level of Common Interest for Geosphere Sub-Domains.



<table>
<tr><th colspan="6">1.6.1 Fracture Filling</th></tr>
<tr><td colspan="3" rowspan="2">Background
Most groundwater flow and thus radionuclide migration in higher-strength rocks takes place through a network of interconnected fractures. Fractures will be filled with precipitating minerals over time. How this happens will depend on various factors, including temperature and time. This could influence the porosity, permeability, organic surface coating, microbial community, and eventually the sorption coefficients of long-lived radionuclides on mineral surfaces.
EC Projects: CROCK</td><td colspan="3">Research Needs/Driver
A thorough understanding of the processes of fracture filling by precipitating minerals is required to support the safety case for a geological disposal facility in higher strength rock.</td></tr>
<tr><td colspan="3">Research Objectives
To further understanding of this sub-domain, an activity could analyse 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.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

1.6.2 Geological Uncertainties

Background	Research Needs/Driver
A methodology for the quantification of uncertainty is necessary in many technical areas of the programme to develop a GDF. In particular, the need to demonstrate safety over very long timescales post-closure requires an appropriate treatment of uncertainties. The development and use of appropriate assessment methodologies are essential for building confidence in the results of a safety assessment. As uncertainties (epistemic and stochastic) are always associated with assessment results, the substantiation that they have been properly identified, characterized and managed is required.	Further research is required to identify, characterize and manage uncertainties related to site characteristics. **Research Objectives** To develop the state-of-the-art on the management of uncertainties associated with site characteristics, specifically possible geodynamics and tectonic perturbations of the site in the long-term.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.6.3 Groundwater Evolution

Background	Research Needs/Driver
An important requirement of the safety assessment is to be able to demonstrate the long-term chemical stability and low flow conditions of the groundwater system at facility relevant depth over the period of time during which the waste will be a hazard. Groundwater composition and flow patterns may be altered by past and future events, e.g. glaciation events and related subglacial erosion and permafrost formation.	Studies are required to model how past and future events could affect the chemistry and flow of groundwater in some crystalline and clay geological environments, and if these changes could have a detrimental impact on a facility. **Research Objectives** 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.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

1.6.4 Rock-Matrix Diffusion

Background	Research Needs/Driver
Groundwater flow can take place through networks of interconnected fractures. However, much of the porosity and mineral surfaces in fractured rocks occurs not in the fractures, but in the rock between the fractures (the rock 'matrix'). Radionuclide migration through the geosphere would be slowed if this additional porosity and surface can be accessed. The mechanism by which radionuclides are transported through the pore water into the low permeability rock matrix is diffusion. In the context of diffusive transfer between fracture and rock matrix, the process is termed 'rock-matrix diffusion'.	For very long-lived radionuclides it would be beneficial in the development of safety cases to gain improved understanding of the impact of rock-matrix diffusion on travel time through the geosphere. **Research Objectives** To further understanding in rock-matrix diffusion and ensure learning from more advanced Member States is disseminated to less advanced programmes.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium		Low	✓

1.6.5 Site Descriptive Models					
Background Site Descriptive Models are developed based on the data obtained during site characterisation. A Site Descriptive Model describes the geometry and properties of bedrock and water, and the associated interacting processes and mechanisms of a site. This provides the understanding of the characteristics of the site sufficient to allow further qualitative and quantitative modelling to be undertaken as part of the Environmental Safety Case.			**Research Needs/Driver** To maintain and develop understanding of tools and techniques for developing site descriptive models. **Research Objectives** 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.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High	✓	Medium		Low	

5.2 Strategic Theme 2: Building Confidence

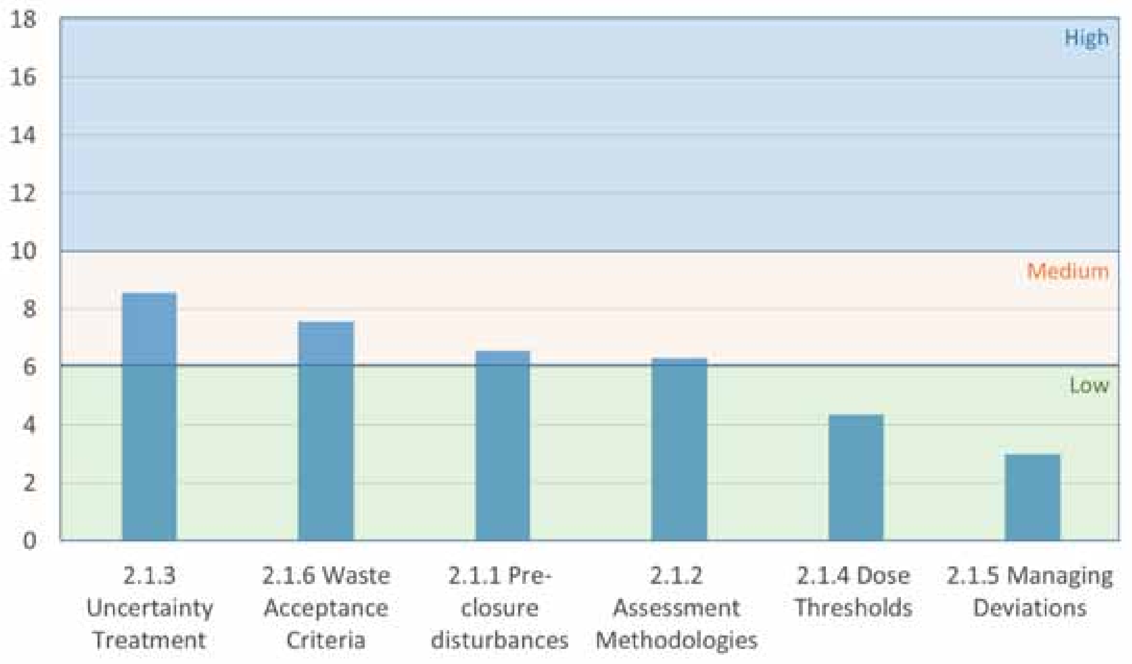
2.1 Safety Case

The safety case for a geological disposal facility may be broadly defined as *"a collection of technical, scientific, administrative and managerial arguments and evidence in support of the safety of a facility"*[14]. It aims to demonstrate that the facility will function according to prescribed requirements. As the safety case is a key input to support the decision to move through successive phases of a disposal programme, improved exchanges on methodologies, continued development of robust tools, and open access to knowledge of good practice are required to continue to improve safety case development, communication, and regulatory review.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 11 below.

2.1.1 Pre-closure disturbances;
2.1.2 Assessment Methodologies;
2.1.3 Uncertainty Treatment;
2.1.4 Dose Thresholds;
2.1.5 Managing Deviations;
2.1.6 Waste Acceptance Criteria.

Figure 31: Level of Common Interest for Safety Case Sub-Domains



[14] IAEA (2012) The safety case and safety assessment for the disposal of radioactive waste specific safety guide, IAEA Safety Standards Series No. SSG-23.

<table>
<tr><th colspan="6">2.1.1 Pre-Closure Disturbances</th></tr>
<tr><td colspan="2" rowspan="2">Background
Feedback, improved data and ongoing monitoring of the facility during construction, operations and closure will inevitability lead to iteration and periodic update of the safety case. This includes disturbances during the operational phase from accidents. In preparation for this, sharing of good practice and co-development of common approaches are required on how to appropriately maintain facility safety assessments, continue assurance of operational safety and confirm that actual conditions are consistent with the assumptions made in the underpinning long-term safety cases used for final licensing. The ageing of safety structures and components is of particular concern for operations over periods of one hundred years.</td><td colspan="4">Research Needs/Driver
Understanding the influence of pre-closure disturbances on long-term safety.</td></tr>
<tr><td colspan="4">Research Objectives
To develop common approaches (including scenarios) for safety case adaptation and update during facility operations and closure.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.1.2 Assessment Methodologies</th></tr>
<tr><td colspan="2" rowspan="2">Background
The development and use of appropriate assessment methodologies are essential for building confidence in the results of the safety assessment of a geological disposal facility. Scope identified includes data clearance, comprehensiveness checking, synthesis of evidence, safety arguments and analyses. Of particular importance is the management of interactions and iteration between safety assessments, design development and adaptation, and data acquisition activities such as site characterisation, research, technology demonstration, and monitoring.</td><td colspan="4">Research Needs/Driver
As different disposal programmes adopt national-specific approaches to conduct safety assessments, there is a requirement to continue to share good practice internationally and continue development of advanced methodologies for construction and facility licensing.</td></tr>
<tr><td colspan="4">Research Objectives
Further research, transfer of knowledge and review of good practice on general methodologies for the safety assessment identifying the different components and activities of a safety assessment.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

2.1.3 Uncertainty Treatment					
Background Site and system-specific safety assessments form an essential basis for the performance assessment of a geological disposal facility. A key challenge is the safety assessment for long timescales recognising the respective uncertainties. In order to increase confidence completeness, consistency and advanced state-of-the-art of the different means and methods used for safety assessments have to be continuously reviewed and compared. Overall, a logical framework for all activities required in the assessment, evaluation, enhancement and communication of the safety case is required at a European level.			**Research Needs/Driver** Increase confidence in and further refinement of methods to make sensitivity and uncertainty analyses. **Research Objectives** Develop common approaches to demonstrate operational and post-closure safety margins and overall facility lifecycle evolution. Improved uncertainty treatment (models and data) using more realistic evolution scenarios (i.e. improved system representation during different timescales and for complex scenarios such as those involving multiple strongly coupled processes).		
Implementation Driven					✓
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium	✓	Low	

2.1.4 Dose Thresholds					
Background Dose thresholds, based on internationally recognised epidemiology studies, provide the basis for the assessment of radiological impacts resulting from nuclear operations. Provision of more relevant low-dose data may lead to refinement of these dose limits. Future doses are modelled on the basis of a series of environmental scenarios based upon climate state and land use.			**Research Needs/Driver** The radiological impact of low doses over the short and long term is an area of ongoing regulatory and stakeholder interest. **Research Objectives** 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.		
Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium		Low	✓

<table>
<tr><th colspan="6">2.1.5 Managing Deviations</th></tr>
<tr><td colspan="3" rowspan="2">Background
The performance assessment of a disposal facility needs to take account of high probability normal / expected evolution scenarios, in addition to low likelihood, but high impact evolution scenarios.
Scenarios for improved treatment and communication include: deviations from as-planned implementation and closure on safety, including the operational phase (and longer than planned storage), delay in repository closure decisions, extreme perturbations and possible outcomes (Bayesian Networks) and accidents / incidents.</td><td colspan="3">Research Needs/Driver
Improved understanding of the impact of deviations in planned implementation scenarios have on the performance assessment outputs of the disposal facility.</td></tr>
<tr><td colspan="3">Research Objectives
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.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">2.1.6 Waste Acceptance Criteria</th></tr>
<tr><td colspan="3" rowspan="2">Background
Waste acceptance criteria are a key requirement for each 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.</td><td colspan="3">Research Needs/Driver
Increase confidence in, and further refinement of, inventory uncertainty quantification methods, including sensitivity studies.</td></tr>
<tr><td colspan="3">Research Objectives
To develop good practice guides for the derivation of waste acceptance criteria.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

2.2 Post-closure process modelling and upscaling

To evaluate the long-term evolution of all disposal facility components, a sufficient understanding of thermal hydro mechanical and chemical (THMC) processes is needed. In this process analysis it is necessary to integrate:

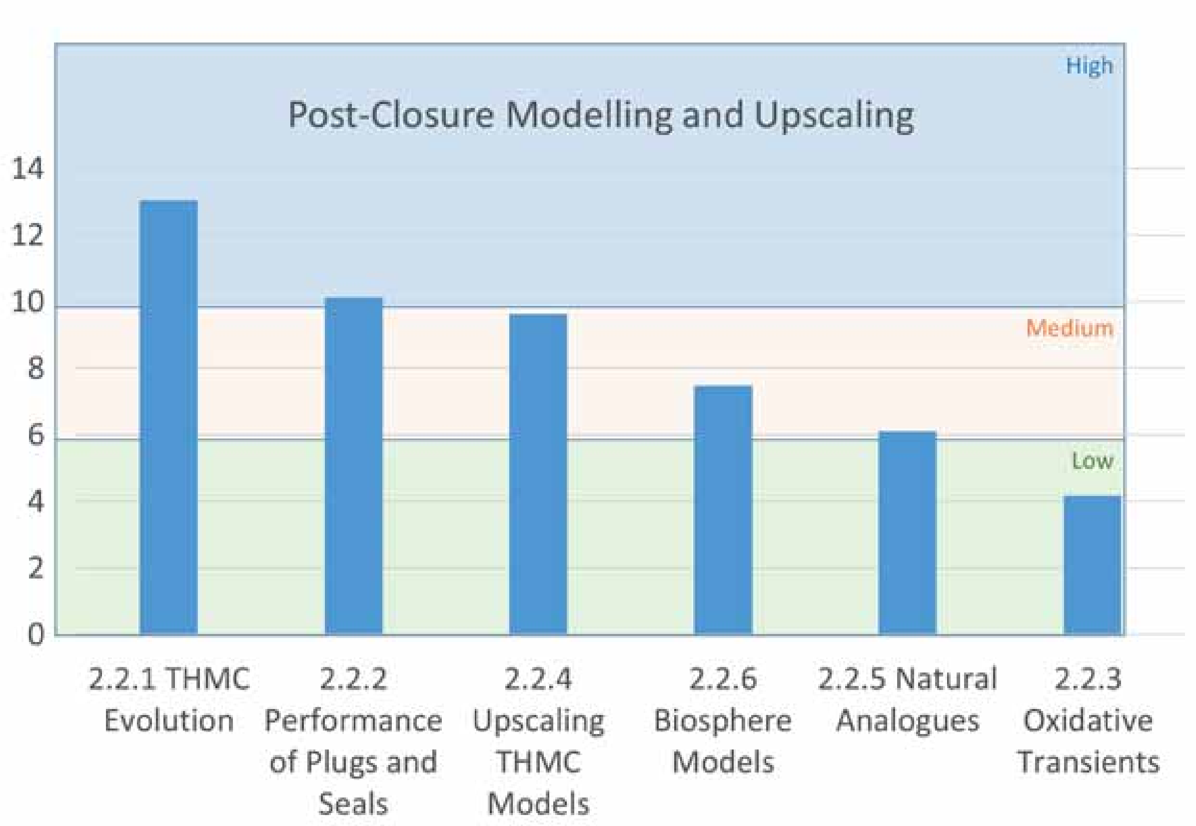
- Component material descriptions and their degradation during storage periods, together with understanding of post-closure evolution descriptions, particularly the transition from the non-saturated system to fully saturated one;
- The potential development of microorganisms which can catalyse certain 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;
- 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 the most relevant ones for performance 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.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 12 below.

2.2.1 THMC Evolution;
2.2.2 Performance of Plugs and Seals;
2.2.3 Oxidative Transients;
2.2.4 Upscaling THMC Models;
2.2.5 Natural Analogues;
2.2.6 Biosphere Models.

Figure 42: Level of Common Interest for Post-Closure Process Modelling and Upscaling Sub-Domains.



<table>
<tr><th colspan="6">2.2.1 THMC Evolution</th></tr>
<tr><td colspan="3" rowspan="2">Background
The long-term performance of the near-field rock, EDZ and engineered barriers (e.g. bentonite) may be affected by coupled THMC process evolution, including resaturation. It is necessary to understand the impacts of thermo-hydrogeochemical evolution on the long-term performance of near field rock, concrete structures or bentonite buffer interactions. The effect of temperatures >150°C on bentonite buffer evolution should be considered for some disposal concepts. It is also necessary to consider the inclusion of thermo-hydro-mechanical evolution and impact on the EDZ.
Some wastes may also produce gas when they come into contact with water; understanding of the coupling between water and gas should therefore be taken into account.
EC Projects: BENCHPAR, HE (Heater Experiment)</td><td colspan="3">Research Needs/Driver
A safe and robust design for the disposal concept for HLW requires detailed knowledge about the THMC behavior of the host rock and the buffer materials.</td></tr>
<tr><td colspan="3">Research Objectives
To further understand the impact of THMC on the behavior of the host rock and the buffer materials.
To develop appropriate models coupling all the relevant phenomenology impacting the key processes during the transition from the non-saturated period to saturation following closure.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

2.2.2 Performance of Plugs and Seals					
Background Modelling coupled THMC behavior of plugs and seals can be used to demonstrate how the disposal system performs. A description of the chemical and mechanical performance of seals and plugging systems is necessary, including thermo-physical behaviour and resaturation and consideration of interfaces. The mechanistic modelling of physical processes during the saturation phase, and of their long-term behavior, is important. ***EC Projects: RESEAL II, DOPAS***			**Research Needs/Driver** To further understand the coupled THMC behaviour of plugs and seals throughout the post-closure phase. **Research Objectives** To develop improved modelling capability to provide reassurance over the long-term behaviour of plugs and seals.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

2.2.3 Oxidative Transients					
Background The construction and the operation of a disposal facility will give rise to oxidative transients in the near-field that could affect the safety functions provided by various components (EBS and/or the host rock). An improved understanding of such transients has already been developed in previous EC projects (e.g. BENIPA, NF-PRO, FEBEX). ***EC Projects: BENIPA, NF-PRO, FEBEX***			**Research Needs/Driver** To gain an improved understanding of the spatial extent and evolution with time of oxidative transients, as well as the possible impact on safety functions. **Research Objectives** To investigate the oxidative transient in the near field during the construction and operational phases, notably with regard to corrosion of metallic components.		
Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium		Low	✓

2.2.4 Up-scaling THMC Models					
Background THMC model parameters vary with scale. Technical challenges remain regarding extrapolation of these parameters from small scale to repository-scale. This may include mechanistic understanding of long term evolution of mechanical properties, permeability, porosity, creep, or self-healing of fractures. This requires a combination of both modelling and experiments.			**Research Needs/Driver** There is a need to understand the upscaling of THMC modelling for coupled hydro-mechanical-chemical processes in time and space, and the study of its validity and representativeness at all scales and identification of representative volumes. **Research Objectives** To extend deterministic and/or stochastic approaches to take into account the upscaling aspects regarding THM parameters.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

2.2.5 Natural Analogues					
Background Natural analogues are used to provide confidence in the long-term, large-scale processes expected in nuclear waste disposal. The following processes are examples of the use of natural analogues: chemical element diffusion, radionuclide interactions with minerals, iron corrosion, glass alteration and alkaline perturbation. Characterization of natural analogue sites is used to test the relevance and the robustness of models developed from laboratory experiments. Many natural analogues studies have been undertaken and it is important that the learning from more than three decades is not lost.			**Research Needs/Driver** Verification and confidence-building for long-term, large-scale processes, and upscaling from models to repository scale. **Research Objectives** To promulgate understanding of the use of natural analogues to provide confidence in the long-term, large-scale processes.		
Implementation Driven					
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium	✓	Low	

2.2.6 Biosphere Models					
Background Understanding the behaviour of radioactivity in marine, terrestrial and atmospheric systems is done via biosphere modelling, supported by a range of climate evolution scenarios which bound the uncertainty in future human and non-human biota activity. ***EC Projects: BIOCLIM, BIOMOSA***			**Research Needs/Driver** To enhance understanding of biosphere processes so as to improve safety case confidence. **Research Objectives** To enhance the treatment of climate change, non-human biota, land-use and parameter derivation.		
Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

2.3 Numerical Tools

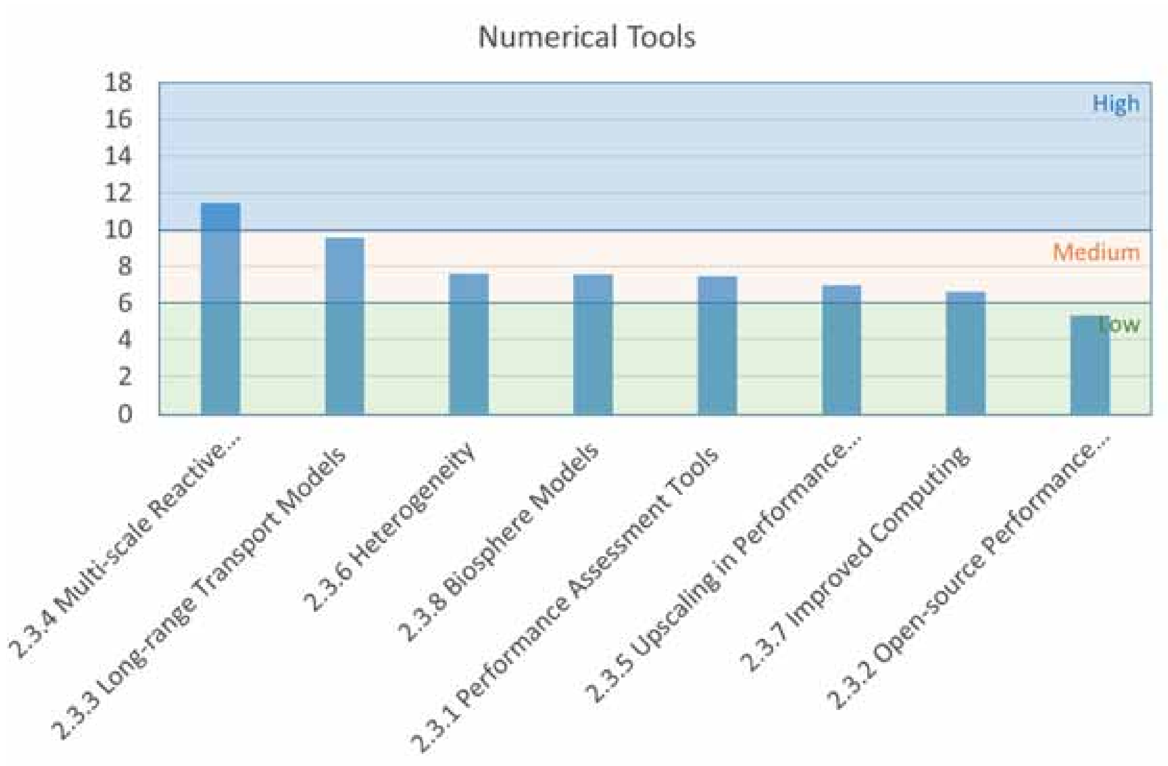
Understanding of physio-chemical processes affecting the evolution of disposal components and geological systems, and their consequences on radionuclide transfer, is based on both an experimental approach and the use of predictive modelling at different temporal and spatial scales. Relevance of modelling 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;
- Multiple-process modelling, including development of algorithms and numerical methods for strong couplings at the large scale. 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 (parallel solvers, domain decomposition, grid adaptation, scalability, etc.), allowing representation of complex integrated and heterogeneous systems; and
- Management and treatment of uncertainties (epistemic, stochastic) in complex models, in order to identify the key input data of the integrated system;
- Enhance understanding of biosphere processes so as to improve safety case confidence.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 13 below.

2.3.1 Performance Assessment Tools;
2.3.2 Open-source Performance Assessment Code;
2.3.3 Long-range Transport Models;
2.3.4 Multi-scale Reactive Transport Models;
2.3.5 Upscaling in Performance Assessment;
2.3.6 Heterogeneity;
2.3.7 Improved Computing.

Figure 13: Level of Common Interest for Numerical Tools Sub-Domains.



<table>
<tr><th colspan="6">2.3.1 Performance Assessment Tools</th></tr>
<tr><td colspan="3" rowspan="2">Background
Today, numerical simulation is a very efficient tool to address the complexity of flow and transport of radionuclides in porous media at large time and space scales. However, the results depend on the accuracy of the input data and the influence of each input parameter might also be difficult to quantify. As a consequence, many methods to treat uncertainties have been developed (neural network, polynomial, chaos, etc.) but these methods are still time consuming or do not utilise the most recent and efficient mathematical algorithms.</td><td colspan="3">Research Needs/Driver
Improved mathematical methods to: (i) analyse the importance of physical properties defined as input of a simulation on the relevant output of the simulation (sensitivity analysis) and (ii) quantify the effect of uncertainties on these outputs (uncertainty analysis).</td></tr>
<tr><td colspan="3">Research Objectives
To develop a tool which includes algorithms that can be coupled to any kind of numerical code and provide relevant indicators to help analysis of the data quality and the confidence of the result.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.3.2 Open-source Performance Assessment Code</th></tr>
<tr><td colspan="2" rowspan="2">Background
In the domain of unsaturated and multiphase flow and transport in porous media, the current leading numerical assessment code has been developed in Berkeley (USA). Its success comes from its open source model which allows researchers from all over the world to test their own model easily. However, in terms of performance, this code does not benefit from modern algorithms or numerical schema which can lead to poor performance or even crashes.</td><td colspan="4">Research Needs/Driver
To develop a High Performance Computing oriented code which can simulate multiphase flow and transport in unsaturated porous media.</td></tr>
<tr><td colspan="4">Research Objectives
To develop a parallel tool for the simulation of complex and large models of multiphase flow and transport. The open source approach should allow the code to be updated efficiently to benefit from new physical models or better numerical solvers.
The code should be as efficient as possible in order to address numerical models including up to hundreds of millions of cells in reasonable time. This requires the use of state-of-the-art parallel algorithms and/or optimized numerical method and schema.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">2.3.3 Long-range Transport Models</th></tr>
<tr><td colspan="2" rowspan="2">Background
The migration of contamination from the repository through the geosphere is based on advective-diffusive transport models which take into account the properties of the geosphere, including geometry, hydrodynamics, and other geological phenomena (weathering, erosion, glacial phenomena, overburden, etc.). Natural tracers can be used to verify models.</td><td colspan="4">Research Needs/Driver
There is the potential to improve the representation of the transport of contamination through the geosphere in support of the safety case.</td></tr>
<tr><td colspan="4">Research Objectives
To extend and verify robust geosphere transport models.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

2.3.4 Multi-scale Reactive Transport Models

Background The migration of contaminants (including radionuclides, non-radiological pollutants, etc.) from the repository is driven by complex mechanisms including, e.g. aqueous speciation, surface retention processes and multi-species driven transport. Multi-scale reactive transport modelling enables the consideration of processes described at different scales. Laboratory and in-situ experiments may be used for model validation.	**Research Needs/Driver** To further develop the capability to model the migration of contaminants from the repository to the biosphere. **Research Objectives** To develop improved multi-scale reactive transport models.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

2.3.5 Upscaling in Support of Performance Assessment

Background Up-scaling strategies (including bottom-up approaches) are developed to support and justify hypotheses, parameters and models used in performance assessment calculations. They are based on the understanding and modelling of the fundamental processes from the micro to macroscopic scale taking into account spatial heterogeneity, including multi-scale structuration of rocks/materials.	**Research Needs/Driver** Understanding the role of physical/chemical processes at different scales and linking bottom-up and top-down approaches in performance assessments. **Research Objectives** 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.). To develop multi-scale strategies to represent complex phenomena (redox processes, microbiology, mineral transformation, etc.).

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

2.3.6 Heterogeneity

Background The near and far field surrounding a Geological Disposal Facility is likely to be subject to heterogeneities which are unlikely to be fully represented in models, e.g. from a flow point of view, heterogeneities are either generated by the construction of the repository (voids, EDZ, etc.) or exist locally in the geological environment. Integrated modelling taking into account the heterogeneities can provide significant benefits.	**Research Needs/Driver** To undertake phenomenological and safety studies to take into account heterogeneities of the system (mineralogy, hydrology, water composition, permeability, porosity, fracture networks). **Research Objectives** To provide a modelling capability which can integrate available site data to account for heterogeneities in the near field.

Implementation Driven					
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium	✓	Low	

<table>
<tr><th colspan="6">2.3.7 Improved Computing</th></tr>
<tr><td rowspan="2">Background
High performance computing is currently a subject of high interest in order to reduce the duration of simulations.</td><td colspan="5">Research Needs/Driver
To develop an innovative method to parallelize and distribute computation automatically on different computing materials (CPU, GPU, heterogeneous cluster and grid, etc.) with respect to the characteristics and available resources of each material.</td></tr>
<tr><td colspan="5">Research Objectives
To enable the use of numerical and highly parallelized code on a heterogeneous grid or cluster, especially in the following range of applications: 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, THM couplings at a large scale.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

2.4 Operational Safety

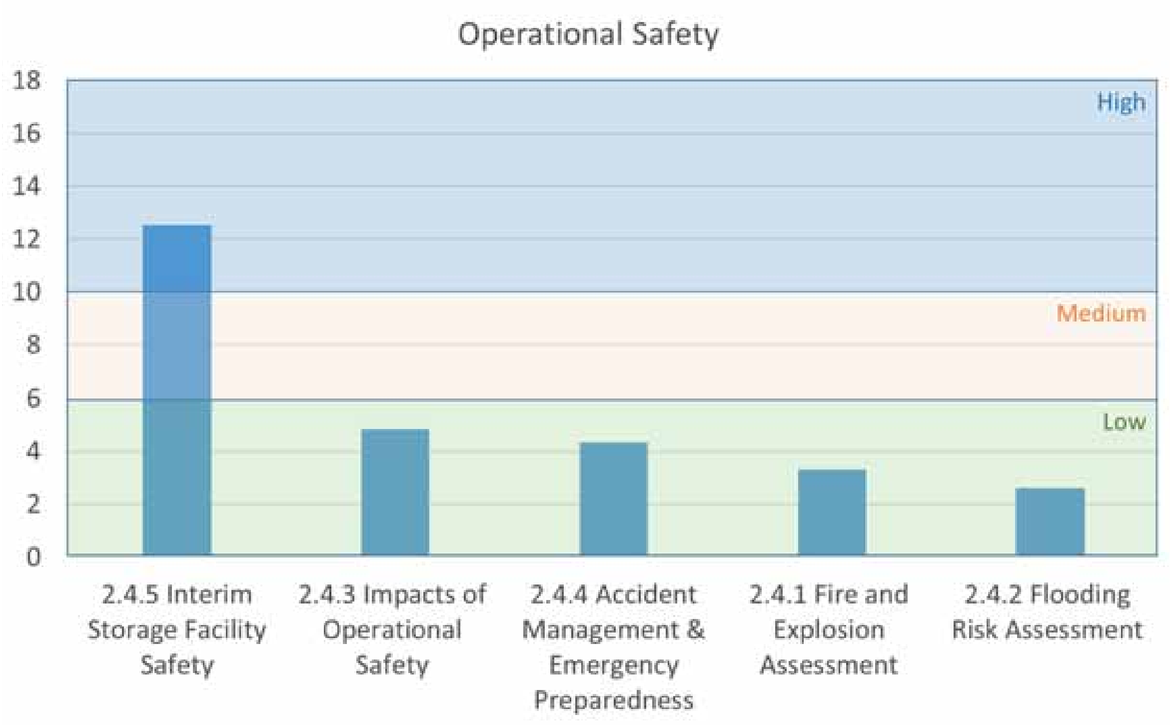
A disposal facility is designed, built and operated on the basis of a number of safety and technical requirements and assumptions. Their common driver is to ensure the prescribed level of human and environmental safety throughout the facility lifecycle. However, during the facility development and operations, deviations from the planned processes could be anticipated; some might be initiated by human errors, others by the lack of information about the host rock structures or behaviour; poorly controlled modifications from proposed technologies and materials might be another initiating mechanism. All these events may result in consequences in terms of operational and / or long-term safety. These events, even where less probable, should be thoroughly assessed so that they can be eliminated or otherwise mitigated through design or other controls.

Research topics regarding the operational phase of a disposal facility may include the assessment of potential accidental situations and their consequences and evaluation of Engineered Barrier System components and the host rock during facility operation; and the development of a European accident management and emergency preparedness database.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 14 below.

2.4.1 Fire and Explosion Assessment;
2.4.2 Flooding Risk Assessment;
2.4.3 Impacts of Operational Safety;
2.4.4 Accident Management and Emergency Preparedness;
2.4.5 Interim Storage Facility Safety.

Figure 14: Level of Common Interest for Operational Safety Sub-Domains



<table>
<tr><th colspan="6">2.4.1 Fire and Explosion Assessment</th></tr>
<tr><td colspan="2" rowspan="2">Background
Preventing a release of radioactivity due to a fire or an explosion is a very important principle during the operational phase of a geological disposal facility. This includes requirements from both the underground (mining) and nuclear regulations.</td><td colspan="4">Research Needs/Driver
To assess the impact of fire or explosions on the underground systems during the operational phase.</td></tr>
<tr><td colspan="4">Research Objectives
To develop improved understanding and modelling tools to simulate the behaviour of a fire and the generated smoke in galleries and disposal vaults. In the case of a fire, the behaviour of the packages from some waste streams (such as bitumen encapsulated waste), as well as that of concrete overpacks, concrete liner and even the host-rock (locally) would benefit from further study.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">2.4.2 Flooding Risk Assessment</th></tr>
<tr><td colspan="2" rowspan="2">Background
Excessive ingress of water in a disposal facility, either from the geological formation or from the surface, may jeopardize operational as well as long term safety and performance. All potential pathways for water penetration need to be identified and potential consequences assessed.</td><td colspan="4">Research Needs/Driver
Assessment of any potential and resulting impact of excessive ingress of water in the disposal system.</td></tr>
<tr><td colspan="4">Research Objectives
To identify potential pathways for water ingress from representative geological disposal facility designs.
To assess impacts of facility flooding on operational safety and long-term safety and performance.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">2.4.3 Impacts of Operational Safety</th></tr>
<tr><td colspan="2" rowspan="2">Background
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 repository system.

It would be beneficial to share lessons learned from other operational experience, incidents and accidents internationally.</td><td colspan="4">Research Needs/Driver
To minimise the disturbance of operations on long-term facility safety it would be beneficial to share lessons learned from other geological disposal facilities as well as mining operations and conventional nuclear facilities.</td></tr>
<tr><td colspan="4">Research Objectives
To identify scenarios and analyse the consequences on disposal related to disturbances caused during construction and operation of the facility.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

2.4.4 Accident Management and Emergency Preparedness					
Background Reporting systems have been established to accumulate and disseminate information on accidents. The reports contain information on events of safety significance with important lessons learned. These experiences assist in reducing or eliminating the likelihood of the recurrence of similar events at other facilities, e.g. in nuclear generation, the INES (International Nuclear Event Scale) and IRS (Incident Reporting System) have existed for many years. A complementary reporting system could be set up to collect significant event data and analyse them in order to give a safety related overview of waste management practices.	**Research Needs/Driver** To improve the understanding of potential safety issues with regards to radioactive waste management. **Research Objectives** To identify good practice in the management of radioactive waste disposal from lessons learned.				
Implementation Driven	✓				
Transfer of Knowledge to LAPs	✓				
Level of Common Interest					
High		Medium		Low	✓

2.4.5 Interim Storage Facility Safety					
Background The operating lifetime of interim storage facilities is constrained by periodic safety assessments, which consider factors such as external attacks, earthquake resistance, aircraft accidents, monitoring/assessment of facilities with regards to ageing, monitoring/assessment of the performance of tanks for the storage of liquid waste, etc. Good practices with respect to the design criteria for new storage facilities are also of interest.	**Research Needs/Driver** To share information about the operational lifespan of interim storage facilities and to provide guidelines on how to manage the safety assessment of such facilities (further than in the IAEA Interim Storage of Radioactive Waste Packages Technical Report Series No. 390). **Research Objectives** To review and further develop guidance on the operational lifespan of interim storage facilities and to provide guidelines on how to manage the safety assessment of the facilities.				
Implementation Driven	✓				
Transfer of Knowledge to LAPs					
Level of Common Interest					
High	✓	Medium		Low	

2.5 Practical Implementation

There is a need to demonstrate that the concept for disposal is practical in terms of its 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.

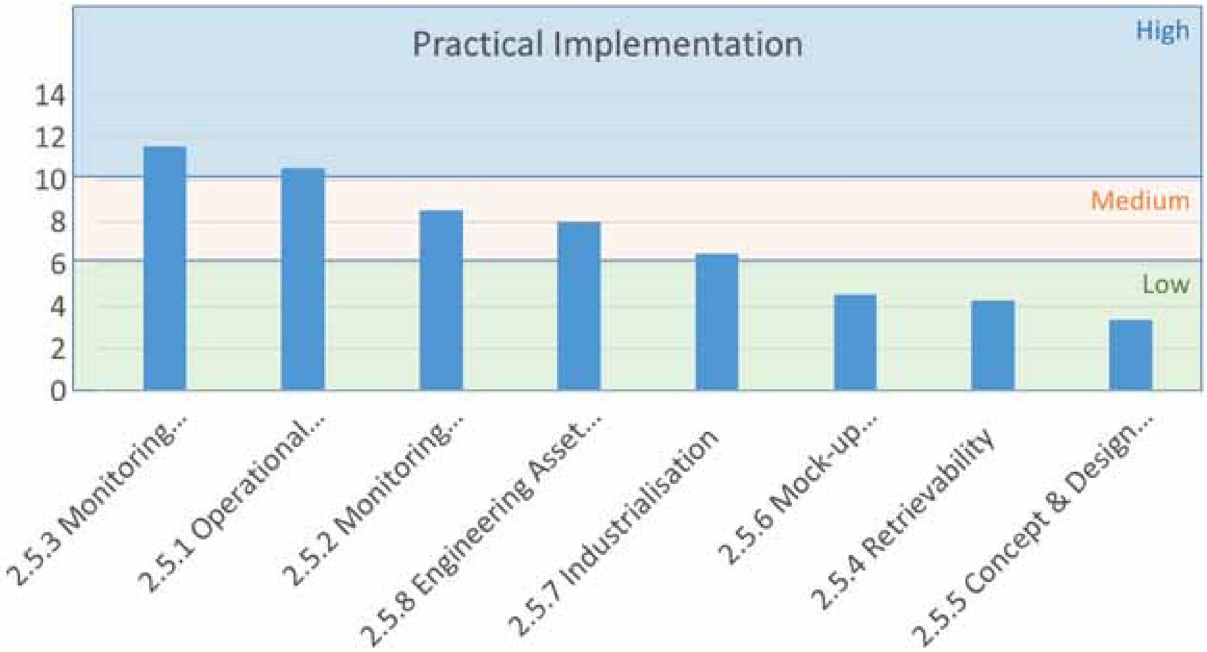
In addition, during disposal facility operations there will be an ongoing need to evaluate the behaviour of key components of the repository system, or the impacts of the repository and its operation on the environment – and thus to support decision making during the disposal process and to enhance confidence 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.

The sub-domains are listed below, and the specific scope, drivers and background for each are provided in the sub-domain tables below. The levels of common interest for the sub-domains are shown in Figure 15 below.

2.5.1 Operational Monitoring Strategies;
2.5.2 Monitoring Strategies for Closure and Post-Closure;
2.5.3 Monitoring Technologies;
2.5.4 Retrievability;
2.5.5 Concept & Design Adaptation;
2.5.6 Mock-Up Experiments;
2.5.7 Industrialisation;
2.5.8 Engineering Asset Management.

A further sub-domain, 2.5.8 Engineering Asset Management, was added post-consultation based on a consensus view which agreed with consultation feedback that this was missing from the original domain scope.

Figure 15: Level of Common Interest for Practical Implementation Sub-Domains



<table>
<tr><th colspan="6">2.5.1 Operational Monitoring Strategies</th></tr>
<tr><td colspan="3" rowspan="2">Background
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).
The EC MODERN and MODERN2020 projects have provided significant progress in this area.
EC Projects: SOMOS, MoDeRn, MoDeRn 2020</td><td colspan="3">Research Needs/Driver
To develop 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.</td></tr>
<tr><td colspan="3">Research Objectives
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.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.5.2 Monitoring Strategies for Closure and Post-closure</th></tr>
<tr><td colspan="3" rowspan="2">Background
The post-closure phase will begin when the repository access ways have been backfilled and sealed. Some programmes may choose to begin the post-closure phase with a period of institutional control. With or without such a period, monitoring and surveillance could be maintained if society considers it beneficial, although it is a principle of geological disposal that assurance of safety does not require post-closure monitoring. It should be noted also that any post-closure monitoring decided by future generations should be designed in such a way that there are no negative impacts on the performance of the containment barriers and therefore on the long-term safety of the repository would occur. Monitoring during the institutional control period could also form part of the decision process on when to close the facility.</td><td colspan="3">Research Needs/Driver
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.</td></tr>
<tr><td colspan="3">Research Objectives
To select safety parameters and appropriate monitoring technologies (e.g. wireless transmission, large energy autonomy technologies, geophysical techniques) which could provide reassurance of the integrity of geological disposal facilities during a period of post-closure institutional control. In implementing such a strategy it would also be necessary to consider in advance what action would be required in the event that the monitoring equipment gave negative indications and how to determine whether such readings are due to failure of the monitoring equipment rather than the engineered and natural barriers.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.5.3 Monitoring Technologies</th></tr>
<tr><td colspan="3">Background
Although considerable effort has been invested in the development of monitoring technologies 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.
Monitoring systems for a disposal facility may be required to be functional for long periods of time (100 years+). Most monitoring systems for other industries are not designed to function for this length of time and current technologies are unlikely to provide the requisite reliability over such durations.
Online data concepts and data transparency should also be considered.
EC Projects: MoDeRn 2020</td><td colspan="3">Research Needs/Driver
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.

Research Objectives
To develop chemical parameter measurement technologies suitable for the disposal facility environment.
To develop technologies to enable fast geologic mapping of the excavation front to detect faults / shear zones.
To develop architectural elements that enable simple monitoring of the disposal cells.
To develop enhanced data processing technologies (e.g. drift analysis, robot, far field technics, etc.).
To investigate the reliability and robustness of monitoring systems over long time periods, including hardware, software, communications, quality of data and maintenance.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td></td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td>✓</td><td>Medium</td><td></td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.5.4 Retrievability</th></tr>
<tr><td colspan="3">Background
Reversibility is based on governance systems and technical project management systems. Among the technical project management systems, retrievability corresponds to the ability to remove waste packages emplaced in the deep geological formation.
The aim of retrievability is to:
Provide flexibility in operating the repository,
Reconsider the choice of waste packaging method (repackaging) before return to disposal,
Or even reconsider geological disposal as the management method for some or all of the waste during the operating period.
Some technologies to retrieve waste packages were developed and tested within the EC ESDRED project.
EC Projects: ESDRED</td><td colspan="3">Research Needs/Driver
To improve understanding of the following:
Durability of waste packages ensuring their ability to be handled,
Durability of structures ensuring the maintenance of functional free play,
Removal operation performed without jeopardising safety,
Aptitude for dismantling of partial closure components (for cells and drifts) and for reequipping the facility.
Research Objectives
To assess the durability of the different components (waste packages, structures) at long term (about one hundred years)

To develop technologies to retrieve waste packages (e. g. development of robots, sensors…)</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

2.5.5 Concept and Design Adaptation					
Background 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.			**Research Needs/Driver** Assessment of the technical feasibility and lifecycle adaptation of a geological disposal concept for a specific site and specific nuclear waste type. **Research Objectives** 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.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium		Low	✓

2.5.6 Mock-up Experiments					
Background To verify the robustness, and demonstrate feasibility and the reliability, mock up experiments are needed. It would be beneficial to demonstrate the design of several elements such as tunnel seals or high level waste cells at full scale. Mock-ups can be at several scales from metre scale to full scale within URLs. ***EC Projects: LUCOEX***			**Research Needs/Driver** Mock ups are needed, firstly to demonstrate the capacity to build some complex components such as seals or the engineered barriers. Secondly, to demonstrate that each component will perform as expected. **Research Objectives** To improve the robustness of disposal system designs using large scale mock ups.		
Implementation Driven					✓
Transfer of Knowledge to LAPs					
Level of Common Interest					
High		Medium		Low	✓

<table>
<tr><th colspan="6">2.5.7 Industrialization</th></tr>
<tr><td colspan="2" rowspan="2">Background
The industrialization of aspects of implementation of a geological disposal facility may need to be considered. An example of this is industrialization - excavated rock will be reused to backfill tunnels. Long term storage of such material during the operational phase could lead to geochemical transformations. The packaging of backfill materials (pellets, blocks, etc.) must be chosen in such a way as to comply with requirements (e.g. in terms of mechanical stability or hydraulic performance) while remaining compatible with industrial scale application and quality assurance. Other examples could be waste emplacement technologies, retrieval technologies and sealing technologies.</td><td colspan="4">Research Needs/Driver
To develop a robust solution for backfill materials that fulfils the requirements and compatible with an industrial application.</td></tr>
<tr><td colspan="4">Research Objectives
To characterize at various scales (from laboratory scale to demonstrator at full scale) of 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.
The research will help to define the best compromise between the performance of the material (in terms of packaging, basic properties, etc.) and industrial optimization and quality assurance.
Long term behavior of backfill material also needs to be investigated. This includes the development of modelling capacity. Effect of long term storage should also be studied as it could lead to storage recommendations</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td></td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

<table>
<tr><th colspan="6">2.5.8 Engineering Asset Management</th></tr>
<tr><td colspan="2" rowspan="2">Background
‘Asset management’ refers to the strategic plan, processes and actions that are needed to upkeep the 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.</td><td colspan="4">Research Needs/Driver
Nuclear waste deposition facilities will be operational over decades. During this time, a plenitude of maintenance activities and modernisation of assets (including equipment, machinery, infrastructure, real estate, data/computer systems, etc) are required. The requirements arising from the upkeep and improvement of the assets and a preliminary asset management strategy should be defined already in the design phase. Knowledge can be shared to less advanced programs based on international experience.</td></tr>
<tr><td colspan="4">Research Objectives
To develop concepts for cost-effective asset management strategies for a deposition facility.

To develop criteria for managing assets that balances risk, cost and benefit of the assets over their life cycles. Evaluate alternative scenarios for asset management approaches.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest – To be determined - Indicative Score of Medium</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>

5.3 Strategic Theme 3: Integrated Knowledge Management System (IKMS)

'Knowledge' here refers to the scientific and technical knowledge generated in RD&D activities in radioactive waste management, as well as experience from the implementation of disposal programmes.

Establishing and implementing an Integrated Knowledge Management System (IKMS) within the European Joint Programme in radioactive waste management and disposal is motivated by four main objectives that will be met by the deployment of specific activities/tools, outlined in Table 3.

Table 3: Overview of the four main aims, objectives and associated activities/tools to establish and implement an IKMS

<table>
<tr><th>Aims</th><th>Objectives</th><th colspan="2">Activities/tools</th></tr>
<tr><td>1. Preserve/ capitalize knowledge</td><td>Ensure that knowledge is documented, maintained and kept accessible in order to enable present and future waste management programmes and generations to benefit from the knowledge generated through past, on-going and future collaborative activities European level. The emphasis is on scientific-technical knowledge for the expert community.</td><td>Establish, maintain and up-date State of Knowledge Documents.</td><td rowspan="3">Web structured Knowledge Handbook</td></tr>
<tr><td>2. Transfer of knowledge towards Member-States with early-stage RWM programme</td><td>Ensure 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 most advanced national programmes.</td><td>Establish, maintain and up-date State of Knowledge Documents;

Development of guidance documents[15] for establishing and implementing national R&D programmes to support radioactive waste disposal solutions;

Training courses.</td></tr>
<tr><td>3. Transfer of knowledge</td><td>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 radioactive waste management and disposal by providing training and mobility for researchers.</td><td>Establish, maintain and up-date State of Knowledge Documents.

Development of guidance documents for establishing and implementing national R&D programmes to support radioactive waste disposal solutions.

Making use of large infrastructure, (Hot-Lab facilities, URLs, ...) and existing training opportunities (ENEN, ...):

• Training courses;
• Training Mobilities;
• Professional Networking;
• Implementation of specific tools, as identified, for transfer of knowledge to MSs with less advanced implementation levels.</td></tr>
</table>

[15] Taking account of the waste management programme implementation level and size, and level of complexity in the waste inventory.

Aims	Objectives	Activities/tools
4. Collate and disseminate knowledge	Establish and implement a dissemination strategy with specific actions adapted to each target group[16] that will show the added-value and maximise the impact of the European Joint Programme, notably in achieving scientific excellence, contributing to competitiveness, solving societal challenges and achieving a high-level of engagement.	Dissemination and demonstration of progress, results and added-value of the European Joint Programme to a wide audience, including consideration of: • Annual EJP meetings with scientific-technical proceedings; • Media-events • Reports for Policy and Decision makers; • Presentation of the EJP outcome at international conferences and events; • Interaction and exchange with international organizations.
5. Identify knowledge needs	When needed, carry out strategic studies in support of national programmes, e.g. identifying where a common understanding on a particular topic needs to be reach and if necessary, elaborate upon how to proceed with this topic (RD&D activities, knowledge management activities, position paper, etc.)	• Strategic studies (Networking Activity WPs).

The suggested tools/activities are described in more detail below. The outcomes of these activities will be accessible via the Web-structured Knowledge Handbook.

5.3.1 State-of-Knowledge Documents

Knowledge Handbook			
Background Scientific and technical State-of-Knowledge (SoK) documents in the field of RWMD will be developed as interactive synthesis with the aims of documenting, disseminating and communicating the state-of-the-art (i.e. where we are today, how we got there, including bibliography and links towards scientific publications, relevant deliverables), remaining uncertainties and knowledge gaps and alternative views and their key differences. The frontier scientific-technical Knowledge, including underlying basic processes, are interlinked in the Knowledge Handbook			**Needs/Driver** There is a need to transfer knowledge between different groups of experts, forthcoming generations of experts, and towards Member-States with early-stage RWM programme implementation. **Objectives** To ensure that Member-States and their different Actors, including those with national programmes at an early-stage of implementation, can take advantage of the broad set of existing knowledge and know-how. Simultaneously, a broadly accepted scientific-technical knowledge base can be expected to become a reference for implementation and assessment of RWMD activities.
Level of Commitment			
Number of Organizations that have committed to developing this proposal		WMO/TSO/RE/ CS/WP/other	
Number of Member States			

[16] Target groups could be: Scientific and technical stakeholders (Joint Programme contributors, waste management organisations, SITEX, research entities, students, early career scientists/engineers, engineering companies, international experts, IAEA, NEA, European Technology platforms, EC, national decision makers, experts from civil society, etc.), local stakeholders and civil society organisations engaged in the proposed EJP (if any), wider public interested in RWM.

5.3.2 Guidance

Guidance			
Background *Descriptive methodological* guidance / good practices shall be established in order to support Member-States in establishing and implementing their national RD&D programme for the safe management of spent fuel and radioactive waste while considering knowledge gaps to be filled in for all steps of RWM activities and individual waste streams, in accordance with the timeframe of their National RWM programme - as required within the Waste Directive (Article 12).			**Needs/Driver** Member States need to have *"the research, development and demonstration activities that are needed in order to implement solutions for the management of spent fuel and radioactive waste;"* (Waste Directive Art. 12.1(f)). **Objectives** Provide Guidance for Member States establishing and implementing national R&D, competence & skills, and transparency programmes, providing the basis for benefiting from the RWMD-EJP.
Level of Commitment			
Number of Organizations that have committed to developing this proposal		WMO/TSO/RE/ CS/WP/other	
Number of Member States			

5.3.3 Training

Training			
Background The scientific-technical expert knowledge of the Knowledge Handbook is turned into practical application through the use by the expert community. The transfer of this knowledge to new experts, or widening of the field of expertise of existing ones, requires specific knowledge transfer activities. Measures to implement such knowledge transfer include, summer school with general topics and specific thematic training modules and training mobility measures. Other knowledge transfer activities such as establishing competence development networks activities are also considered. This is done as an element in support of Member States in them providing for their necessary competence, expertise and skills. Education measures for the more basic elements towards expertise and skills are implemented, to the extent useful, through collaboration with European forums and activities on education and international organisations.			**Needs/Driver** "*Member States shall ensure that the national framework require all parties to make arrangements for education and training for their staff, as well as research and development activities to cover the needs of the national programme for spent fuel and radioactive waste management in order to obtain, maintain and to further develop necessary expertise and skills.*" (Waste Directive, Art. 8) **Objectives** Transfer the scientific-technical Knowledge managed within the knowledge handbook, to the expert community in the different Member States. Thereby, the knowledge transfer is aimed at, in particular maintaining the present expertise, developing next generation of experts, and supporting national programmes in early implementation stages as well as small programmes to develop the necessary expertise.
Level of Commitment			
Number of Organizations that have committed to developing this proposal		WMO/TSO/RE/ CS/WP/other	
Number of Member States			

5.3.4 Exchange and Dissemination of Knowledge

<table>
<tr><th colspan="4">Dissemination tools and channels</th></tr>
<tr><td colspan="3" rowspan="2">Background
There are various dissemination tools and channels that can be deployed to implement the dissemination strategy. The choices of these tools will depend on the main objective of the dissemination, on the target audience and on the messages to be convened: website, newsletters, publications, media events, organisation of workshops/conference, conference participation, etc.</td><td>Needs/Driver
Drivers for dissemination are amongst others, the need for transparency as of Art. 10 of the waste directive:
“Member States shall ensure that necessary information on the management of spent fuel and radioactive waste be made available to workers and the general public....
and
Member States shall ensure that the public be given the necessary opportunities to participate effectively in the decision- making process.......”
Thereby, dissemination of the RWMD-EJP outcome is part of the overall need for justifying the resources used to actors beyond the scientific-technical expert community.</td></tr>
<tr><td>Objectives
The knowledge generated and managed within the RWMD-EJP is disseminated to a broader interested set of actors, including Civil Society, decision and policy makers, waste producers, and a broader interested community through the media.</td></tr>
<tr><td colspan="4">Level of Commitment</td></tr>
<tr><td>Number of Organizations that have committed to developing this proposal</td><td></td><td>WMO/TSO/RE/ CS/WP/other</td><td></td></tr>
<tr><td>Number of Member States</td><td></td><td></td><td></td></tr>
</table>

5.3.5 Networking/Strategic studies

Strategic studies are initiated in order to agree upon needs for future activities, including further specific thematic studies or RD&D. This may also be referred to as ‘think-tank’ 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.

The results of the questionnaire carried out within JOPRAD allowed the identification of some topics that could be suitable for the IKMS, which are outlined below. Tables giving more information on their background, drivers, objectives and prioritisation (as assessed through the JOPRAD project) follow.

3.1 Site Uncertainty Treatment;
3.2 Site Evolution Models;
3.3 Site selection;
3.4 Technical and Socio-political Siting Criteria;
3.5 Inventory Collation & Forecasting;
3.6 Evolution of Waste Inventory;
3.7 Link to Waste Producers/Fuel Manufacturers;
3.8 Concept Adaptation and Optimisation;
3.9 Safety Case Guidelines, Management & Review.
3.10 Disused Sealed Radioactive Sources;
3.11 Pre-licensing Management;

3.12 Radiation Protection Optimisation Principle;
3.13 Information Management (interfacing with NEA RepMet);
3.14 EU Research Infrastructure;
3.15 EU DGR Curricular;
3.16 Reversibility.

3.1 Site Uncertainty Treatment					
Background During the process of site selection for geological disposal, early phases will typically involve consideration of a number of sites with different qualities and, often, limited data that is directly relevant to making judgements on suitability for long-term disposal. A decision needs to be taken on the number of candidate sites to be taken forward for characterisation. Later this small number will need to be narrowed down to those taken forward for implementation. Early phases of site selection processes will therefore involve substantial uncertainty due to the scarcity of data. Decisions need to be taken that are based upon the best prospects for successful implementation given this uncertainty. How this uncertainty is characterised, communicated and taken into account in the identification of potential candidate sites will be extremely important				**Needs/Driver** There is a need to undertake the site selection process in spite of the presence of considerable uncertainty arising from a paucity of data. **Objectives** 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.	
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High	✓	Medium		Low	

3.2 Site Evolution Models					
Background A site evolution model will be developed based on data obtained during the site characterisation. The site evolution model will describe changes to the geochemical, geotechnical and hydrogeological properties of the disposal facility and the host rock over time.		**Needs/Driver** There is a need to understand how to develop site evolution models, and how to manage data as it is obtained during the site characterisation phase. **Objectives** To further knowledge on site evolution models, and how the geochemical, geotechnical and hydrogeological properties of the disposal facility and the host rock change over time.			
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High	✓	Medium		Low	

3.3 Site Selection Process	
Background A site identification process will be used to evaluate areas within participating communities to identify combinations of surface site and below-ground rock formations which may have the potential to host a geological disposal facility. Potential candidate sites will be assessed against pre-specified criteria taking account of stakeholder perspectives on the relative importance of these criteria. Typically, based on the results of	**Needs/Driver** Member States and their national implementing bodies have a need to identify potential sites for disposal of their radioactive wastes.

the assessment the disposal facility implementer will recommend to Government which (if any) of the sites could be taken forward for further investigation. The Government would then decide which site(s) will be taken forward. Such assessment criteria could include: geological setting; potential health impact on people; potential impact on the natural environment and landscape; effect on local socio-economic conditions; transport and infrastructure provision; cost, timing and ease of implementation.	**Objectives** To develop a process reflecting best practice when deciding upon the optimum site for geological disposal.
Transfer of Knowledge to LAPs	✓
Level of Common Interest	

High		Medium	✓	Low	

3.4 Technical and Socio-Political Siting Criteria

Background Siting of a disposal facility will require close understanding between technical and socio-political groups. When a facility is closed, and whether the closure is partial, or full, will need to be decided between both technical and socio-political groups.	**Needs/Driver** WMO's have a need to implement a disposal facility, including the full life cycle of the facility, of which closure is an important step. **Objectives** To examine the technical and socio-political criteria on which a partial or full closure 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.
Transfer of Knowledge to LAPs	✓
Level of Common Interest	

High		Medium		Low	✓

3.5 Inventory Collation & Forecasting

Background In order to implement a facility for disposal of wastes, an inventory must first be developed. An inventory will include categorised waste volumes based on known wastes, and forecast wastes likely to be produced in the future.	**Needs/Driver** There is a need to ensure that all countries implementing a disposal facility have developed a comprehensive inventory. **Objectives** To transfer knowledge of good practice in inventory collation and forecasting.
Transfer of Knowledge to LAPs	✓
Level of Common Interest	

High		Medium	✓	Low	

3.6 Evolution of Waste Inventory

Background	**Needs/Driver**
Besides the need for R&D activities, there is a common interest in organizing cross-cutting activities on the methodologies applied to define the radionuclide inventories (e.g. use of radionuclide vectors, uncertainties about databases of radionuclide properties).	To further understanding on the evolution of the radionuclide inventory after disposal. **Objectives** A particular example of uncertainty in need of evaluation is the potential impact of neutron activation on the evolution of the radionuclide. inventory after its disposal.

Transfer of Knowledge to LAPs	✓

Level of Common Interest

High		Medium		Low	✓

3.7 Link to Waste Producers/Fuel Manufacturers

Background	**Needs/Driver**
It is important for implementers of a disposal facility to have strong links with the waste producers, to understand the types of waste and volumes of waste arising.	To strengthen the link between implementers and waste producers. **Objectives** To enhance links to fuel manufacturers - horizon scanning of prospective fuels and BU / better knowledge of linear power. To enhance integration of fuel manufacturer vendor and reactor utilities into the process of spent fuel and nuclear waste disposal solutions, in order to understand spent fuel arisings, including those from innovative fuel types.

Transfer of Knowledge to LAPs	✓

Level of Common Interest

High		Medium		Low	✓

3.8 Concept Adaptation and Optimisation

Background	**Needs/Driver**
The feasibility and suitability of a selected or preferred disposal concept(s) is an ongoing activity, involving the review of disposal system design and layout, 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 proposals formulated for an appropriate degree of regulatory control. As disposal programmes progress through successive stages of development, the process for concept adaptation and optimisation requires careful consideration.	Assessment of the technical feasibility and lifecycle adaptation of a geological disposal concept for a specific site and specific nuclear waste type. **Objectives** To develop a common view on areas of significant safety impact with respect to technical feasibility of selected or preferred geological disposal concepts and designs for specific geological settings and waste types. To develop change control approaches to appropriately capture design adaptation and feedback into safety assessments throughout the lifecycle of a geological disposal development programme.

Transfer of Knowledge to LAPs	✓

Level of Common Interest

High		Medium		Low	✓

3.9 Safety Case Guidelines, Management & Review

Background

The lifecycle of a disposal facility consists of several phases, with important work relating to safety achieved throughout e.g. identification of potential sites, the characterization of sites, the development of design concepts and preliminary designs, as well as construction, operation and closure of the facility. In accordance with international safety standards this work should be carried out within the framework of a safety case which collects scientific, technical, administrative and managerial arguments and evidence in support of the safety of the disposal facility.

Experience has been gained with (pre)licensing processes in a number of countries, which could lead to meaningful discussions with countries with less advanced programmes.

Needs/Driver

Evaluation of experience from different countries' arrangements would enable the identification of possible gaps or weaknesses in the expertise function's expectations. A common view on areas of significant safety impact could be identified and proposals formulated for an appropriate degree of regulatory control.

Objectives

The following (pre)licensing issues are of common interest:

- Analysing current available practices and developing guidelines;
- Developing guidance for reviewing the safety case;
- Evolution of the safety case content with the lifecycle of the disposal facility.

Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium	✓	Low	

3.10 Disused Sealed Radioactive Sources

Background

Disposal of radioactive waste is implemented in order to transfer waste into a state of passive safety. However, for comparably small inventories of Disused Sealed Radioactive Sources (DSRS), the requirements and resources for safe storage are modest. Storing DSRS with half-lives that require isolation of the material from the biosphere for longer time-periods than a few years could thus be an option in some cases.

Needs/Driver

Management options are well established, but one question may still be relevant, namely under which conditions safe longer-term storage could be an alternative option to disposal.

Objectives

To conduct a study to elaborate upon R&D and knowledge transfer activities that could support establishment of a common understanding of the potential role of longer-term storage of DSRS as a management option as an alternative to disposal.

Considerations may include:

- Potential impact of improving technology for improved treatment or re-use;
- Potential for loss of memory for a small near-surface repository versus storage (loss of control).

Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium		Low	✓

<table>
<tr><th colspan="6">3.11 Pre-licensing Management</th></tr>
<tr><td colspan="4" rowspan="2">Background
Licensing of geological disposal programmes is a process extending over several years, in some cases of the order of decade(s). If including license up-dating during operation, and licensing of facility closure, the time-span is of the order of a century.
The licensing phase can benefit from up-front activities in the pre-licensing phase. This may include, amongst others, ensuring that different actors are identified and prepared for their tasks, clear definition of processes and a common understanding of how to implement them, a common understanding of what is required in different phases, availability of clear requirements and common understanding of what they are, common understanding of transparency and stakeholder involvement benefits and needs, etc.
A well-structured pre-licensing phase can therefore be vital for successful implementation in the succeeding licensing process.</td><td colspan="2">Needs/Driver
There is a need to make use of the pre-licensing phase in support of successful licensing of geological repositories. This is also true for other waste management projects with extended licensing periods.</td></tr>
<tr><td colspan="2">Objectives
To identify R&D and knowledge transfer needs in support of defining pre-licensing activities that can support success in the licensing phase/process.</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

<table>
<tr><th colspan="6">3.12 Co-disposal Interactions</th></tr>
<tr><td colspan="4" rowspan="2">Background
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 glass, 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. In some national programmes, (co-) disposal of various types of non-heat-generating waste is foreseen for a single geological facility. The main focus for co-disposal R&D is to:
• identify waste types and compositions that can generate plumes problematic for the integrity and retention of other wastes in a facility;
• assess the potential impact on safety; and
• propose remedial actions such as introducing a ‘respect distance’ between respective disposal concepts, or changing conditioning of certain waste types in order to avoid the potential for problematic plumes.</td><td colspan="2">Research Needs/Driver
Optimizing the use of geological facilities by enabling disposal of wastes with a variety of compositions and properties.</td></tr>
<tr><td colspan="2">Research Objectives
To identify R&D or knowledge transfer in support of optimization of disposal of wastes of different characteristic composition and properties in a single geological disposal facility.</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td></td><td>Low</td><td>✓</td></tr>
</table>

3.13 Radiation Protection Optimisation Principle

Background The development of a geological disposal system for radioactive waste requires consideration of the 'radiation protection optimisation principle' during concept selection, design development and ongoing safety analyses within the framework of the safety case. In 2010, an expert group convened by the NEA reviewed international approaches and available guidance and experience, concluding that there are significant differences in the way national programmes approach the requirements of radiation protection during concept and design optimisation.	**Needs/Driver** Development of guidance on how to develop and optimise geological disposal facility designs with respect to the Recommendations of the International Commission on Radiological Protection. ICRP Publication 122. **Objectives** Improved methodologies for applying the principles of 'Best Available Technology' (BAT) and 'As Low As Reasonably Practicable' (ALARP) 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.				
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium		Low	✓

3.14 Information Management (NEA RepMet)

Background Information management, record keeping and maintaining memory are important activities within the context of implementing geological disposal. 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.	**Needs/Driver** To keep information, knowledge and records over the long lead- and implementation-timelines of geological disposal programmes, from pre-licensing through to the post-operational phase. **Objectives** To identify potential R&D and knowledge transfer in support of improving information management, and record and memory keeping in support of geological disposal programmes.				
Transfer of Knowledge to LAPs					✓
Level of Common Interest					
High		Medium	✓	Low	

3.15 EU Research Infrastructure

Background Across Europe there are several	**Needs/Driver** To understand the breadth and depth of research infrastructure across Europe.

organisations within many countries with infrastructure (databases, equipment, capabilities, etc.) relating to the disposal of radioactive waste.	**Objectives** To document the extent of European research infrastructure: databases, equipment, capabilities, etc. To facilitate networking and sustain joint European research infrastructures with state-of-the-art investigative equipment. To establish a database on partner's competencies and establish conditions allowing for transnational access i.e. for advanced light sources, analytical equipment (surface/solution/solid), actinide laboratories, hot cells, radioanalytical labs, underground research facilities and high performance computation, considering in particular allowing access for waste management and disposal programmes at all stages of advancement.

Transfer of Knowledge to LAPs	✓
Level of Common Interest	

High		Medium		Low	
	✓				

3.16 EU DGR Curricular

Background Given the timescales for implementation of geological disposal in the order of tens to hundreds of years, there will be a requirement to consider the management and capture of knowledge. There will be a number of the work force retiring and an associated loss of knowledge and skills. At the same time the waste management sector will be competing with other sectors of industry for young graduate employees. There is an identified need to develop a European curriculum on radioactive waste management and geological disposal of radioactive waste. A considered approach is required to promote quality assurance of training for professionals and education and training programmes in geological disposal. Such an approach could be along the lines of the European Credit system for Vocational Education and Training (ECVET).	**Needs/Driver** To ensure knowledge is managed and disseminated, and that there is competence maintenance, education and training of workforce. **Objectives** To develop a European wide training programme for geological disposal.

Transfer of Knowledge to LAPs	✓
Level of Common Interest	

High		Medium		Low	
					✓

3.17 Reversibility

Background Reversibility describes the ability in principle to reverse decision taken during the progressive implementation of a disposal system. The development of any geological repository for radioactive waste will take place over many decades and should be open to progress in science and technology, to evolving societal demands and to fixing potential implementation errors. In this regard, selecting technologies that are as reversible as possible is a prudent approach. (R&R International Conference and Dialogue, December 2010, Reims). The principle of reversibility should be taken into consideration in planning a disposal facility so that later generations should have the possibility for retrieval during the various stages of implementation of a facility. Such reversibility should also be considered in the design of the repository.	**Needs/Driver** There is strong societal interest in reversibility of decisions or retrievability of waste. Many challenges remain to be addressed with regards to reversibility, including those related to safety and economy. **Objectives** To develop a common positions across Europe, and to exchange good practices.

Transfer of Knowledge to LAPs	✓
Level of Common Interest	

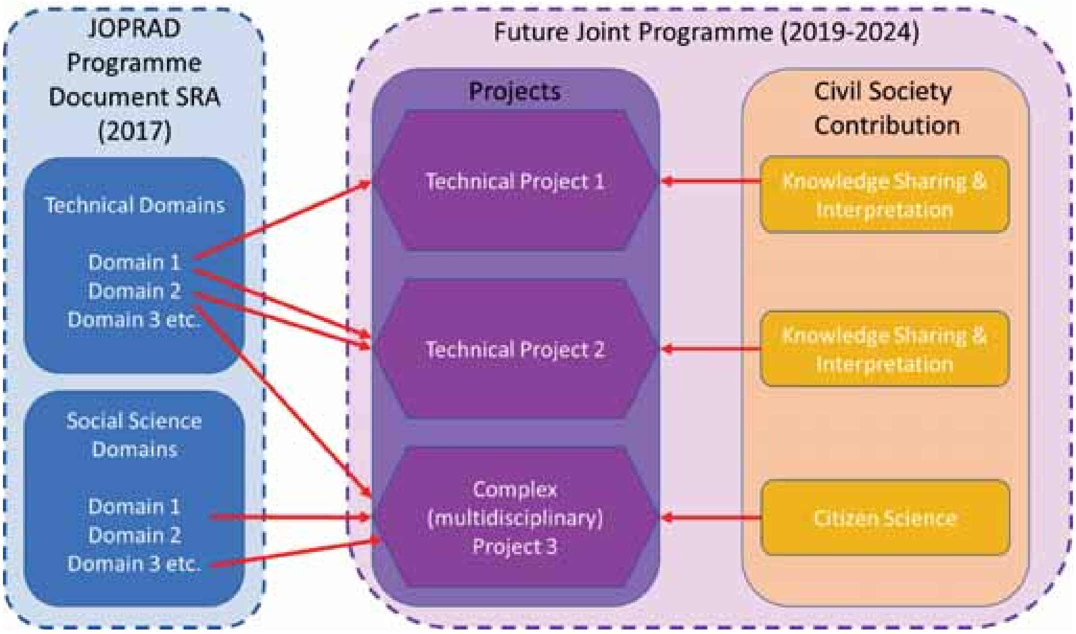
High		Medium		Low	
					✓

6. Socio-Political Cross-Cutting Themes

The SITEX SRA, together with Civil Society representatives involved in JOPRAD have identified specific "socio-political confidence building themes" that may assist in addressing the complexities[17] of radioactive waste management that have been considered during the development of the JOPRAD Programme Document. Geological disposal programmes are integrated (complex, holistic) sociotechnical systems that aim to achieve safe disposal of radioactive waste over long timescales. Such programmes comprise various activities that are integrated so as to make it possible to take sound decisions that involve difficult technical challenges as well as polical, ethical and financial choices and trade-offs. Radioactive waste management has a composite nature and involves a combination of natural resources, technological artefacts, scientific knowledge and expertise, together with social, political and cultural resources. It entails an irreducible dimension of uncertainty that is associated with the (very) long-term dimension of environmental evolution and its potential impact on a Geological Disposal Facility.

Such socio-political themes gather together several social and political factors that have been identified as essential aspects of the development and implementation of geological disposal and which interface with technical themes. The sub-themes outlined in this Section are expected to be addressed (in future research projects) within integrated technical projects where appropriate. In the perspective of better addressing the complexity of Geological Disposal in a future joint programme, it is suggested to take advantage of the socio-political confidence building themes and to incorporate them into "complex/multidisciplinary" research projects involving both technical and non-technical dimensions, as outlined in Figure 16.

Figure 16: Embedding Social and Technical Sciences in a future joint programme.



An exploratory description of several complex/multidisciplinary research projects is available in the deliverable D3.7 of the JOPRAD project [12]

Social and political research activities under a future joint programme are not intended to be self-standing activities separated from the technical aspects of geological disposal. On the contrary, they are intended to be integrated with the other technical and non-technical dimensions involved in order to properly address the complex (holistic) nature of this activity.

[17] Complexity means here the existence of several dimensions of a problem that cannot be addressed and dealt with separately.

The contribution of civil society, as outlined by Figure 17, relates to both more technical and complex research projects:

- **Within more technical research projects** (Technical Project 1 and 2 in Figure 17), civil society may contribute activities of "Knowledge Sharing and Interpretation" (KSI) that would involve interactions with knowledgeable CS experts involved in the research, thus enabling civil society to share, interpret and evaluate the results as the project progresses.
- **Complex/multidisciplinary research projects** (Complex Project 3 in Figure 17), gathering technical scientists and **social scientists,** will also entail specific research methodologies such as **"Citizen Sciences"** (meaning here directly involving people, amateur or non-professional scientists in the production of trustworthy and reliable scientific knowledge).

Three socio-political confidence building themes have been identified:

1. Safety Culture;
2. Uncertainty, Epistemology and Social Trust;
3. Socio-technical Hybridisation and Aggregating a Diversity of People, Stakeholder Engagement.

A brief description of each of the 3 socio-political confidence building themes is given below.

1. Safety Culture	
Background The safety of geological disposal is linked not only with natural or technical factors, but also with the way complexity is managed by human systems. A key challenge is to prevent the specific obsolescence associated with long term compartmentalization (in silo fragmentation) of organisations that compromises their capacity to cope with changes, crisis, ruptures, and evolutions of the world that are likely to occur along the long-term perspective of radioactive waste management. Safety culture is a means for coordinating the various actors engaged around a "common goal" of safety. Particular attention is to be given to safety culture during the (long term) operational phase of geological disposal that relies on active safety management. Rather than being directed toward "public acceptance," efforts can be oriented toward inclusive dialogue steered equally by all parties.	**Needs/Drivers** To ensure that stakeholders and the public are engaged in reviewing the safety of radioactive waste management strategies and geological disposal. **Objectives** To investigate the conditions and means for developing interactions between various categories of stakeholders and the public in the context of enhancing the safety of radioactive waste management strategies and geological disposal.

<table>
<tr><th colspan="2">2. Uncertainty, Epistemology and Social Trust</th></tr>
<tr><td rowspan="2">Background
The inherent uncertainties, as well as the inter-generational dimension of long-term implementation of geological disposal, makes it necessary to understand how social trust building processes may unfold along the stages of a phased decision making process. This will involve uncertainties, for the successive generations of stakeholders at local, national and international levels, investigating whether it is possible for each generation to inherit, actualize and update previous radioactive waste management strategies, achievements, remaining questions and uncertainties, while maintaining social cohesion and solidarity.</td><td>Needs/Driver
To further understand the implementation of epistemological strategies within each generation and along successive generations.</td></tr>
<tr><td>Objectives
To investigate the implementation of epistemological strategies such as “procedural rationality” (involving incremental knowledge building and decision management) and “distributed rationality” mobilizing societal capacities within each generation and along successive generations. This research area could also encompass a historical review of the interactions between the public and the stakeholders in the context of different kinds of hazardous activities (including nuclear and other risks).</td></tr>
</table>

<table>
<tr><th colspan="2">3. Socio-technical Hybridization & Aggregating a Diversity of People, Stakeholder Engagement.</th></tr>
<tr><td rowspan="2">Background
The sustainability of long term governance of geological disposal is linked with the diversity of stakeholders effectively involved (along successive generations), and their capacity to form and maintain common goals and to give meaning to new information and potential disruptive events, along the implementation of geological disposal. This diversity is itself linked with the existence of a comprehensive understanding of geological disposals as hybrids taking on board a diversity of social and technical components that matters for the stakeholders.</td><td>Needs/Driver
To further understanding on socio-technical hybridization of geological disposal implementation strategies.

To further understanding on aggregating a diversity of people, including capacities of collective intelligence regarding radioactive waste management and geological disposal implementation.</td></tr>
<tr><td>Objectives
To examine the conditions and means for enabling the hybridization of technical and social perspectives and the matching of values in the early framing of the problems.

To determine the conditions and means for incorporating new components of society as active stakeholders and potential contributors to the collective intelligence and creativity in order to address the complex issue of radioactive waste management and geological disposal implementation.</td></tr>
</table>

7. Implementation strategy

The Joint Programme in Radioactive Waste Management and Disposal should be seen as a sustainable European network gathering all RD&D Actors sharing together a **Vision** and a RD&D programme for the next 10 -15 years that also includes Knowledge Management and Civil Society engagement aspects.

This shared programme will be described in a self-standing reference document – the **Strategic Research Agenda,** which comprises Section 4 of this document.

When it comes to deploying the Strategic Research Agenda, JOPRAD recommends using the **EC EJP-Cofund tool** which is a 5-year implementation and EC funding tool specifically dedicated to implementing European Joint Research [7].

A **Deployment Strategy** describing the activities that need to be implemented within the next 5 years should be defined and agreed by all Actors and then implemented by submitting an European Joint Programme (EJP) to the EC.

The Joint Programme Implementation Strategy must be backed-up with a **Governance Scheme** that should respect the following principles:

- *Inclusiveness* – i.e. to ensure that the different categories of Actors and Groups of Interest are involved in the definition and implementation of the Joint Programme;
- *Transparency* – i.e. to ensure that decisions are taken in a transparent way, especially regarding how, why and by whom projects and activities are evaluated, selected and implemented;
- *Balance and equity* – i.e. to strive for the highest level of balance and equity by covering interests in RD&D/cross-cutting activities of the different categories of Actors/Groups and by fair distribution of budget;
- *Preservation of independence* – i.e. to avoid conflicts of interests and preserve the independence between the "Expertise function" and the "Implementing function";
- *Flexibility* – i.e. to ensure that new Actors can get involved and that new activities can be launched in the course of an implementation phase.

It is expected that a document entitled 'Setting-Up a European Joint Programme on Radioactive Waste Management and Disposal' will be published later this year.

Acknowledgements

We would like to thank the JOPRAD Working Group 4 for their input to this Programme Document. We also extend our thanks to all colleagues who have engaged and responded to the questionnaire phase of the development of this document, participated in engagement activities and responded to the consultation.

8. REFERENCES

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Appendix 1: Programme Document Working Group Representatives

This Programme Document has been produced by the Programme Document Working Group, including the named representatives from the following organisations across Europe:

- Bernd Grambow CNRS
- Bruno Autrusson IRSN
- Pierre Dick IRSN
- Elisabeth Salat IRSN
- Christophe Serres IRSN
- Tara Beattie MCM
- Ally Clark MCM
- Ellie Scourse MCM
- Jitka Miksova CVREZ
- Lumir Nachmilner CVREZ
- Antonin Vokal SURAO
- Ray Kowe RWM
- Jonathan Martin RWM
- Robert Winsley RWM
- Jacques Delay Andra
- Marie Garcia Andra
- Frederic Plas Andra
- Stéphan Schumacher Andra
- Gunnar Buckau JRC-ITU
- Alexandra van Kalleveen JRC-ITU
- Julien Dewoghélaëre Mutadis
- Gilles Hériard-Dubreuil Mutadis
- Yves Marignac Mutadis
- Valéry Detilleux Bel V
- Pierre Janssen Bel V
- Frank Lemy Bel V

Appendix 2: List of all Organisations contacted with the JOPRAD Questionnaire[18]

Actor Type	Organisation Name	Country	Responded to Questionnaire
RE	**National Centre for Scientific Research (CNRS)**	**France**	Yes
RE	National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	Italy	Yes
RE	National Nuclear Laboratory (NNL)	UK	
RE	University of Pierre and Marie Curie (UPMC)	France	Yes
RE	Belgian Nuclear Research Centre (SCK CEN)	Belgium	Yes
RE	The French Geological Survey (BRGM)	France	Yes
RE	Lithuanian Energy Institute (LEI)	Lithuania	Yes
RE	The French Alternative Energies and Atomic Energy Commission (CEA)	France	Yes
RE	**European Joint Research Centre (JRC)**	**Germany**	
RE	Karlsruhe Institute of Technology (KIT)	Germany	
RE	The Netherlands Organisation for Applied Scientific Research (TNO)	The Netherlands	Yes
RE	Czech Technical University of Prague	Czech Republic	Yes
RE	UJV Rez	Czech Republic	
RE	Technical University of Sofia	Bulgaria	
RE	Instituto Superiore di Sanita	Italy	Yes
RE	Instituto Nazionale di Geofisica e Vulcanologia	Italy	Yes
RE	National Institute of Nuclear Physics (INFN)	Italy	Yes
RE	Delft University of Technology	The Netherlands	
RE	National competence Centre for Industrial Safety and Environmental Protection (INERIS)	France	
RE	Technical University Wien (TUW)	Austria	
RE	University of Natural Resources and Life Sciences (BOKU)	Austria	
RE	Federal Ministry for Economic Affairs and Energy (BMWI)	Germany	Yes
RE	Bulgarian Academy of Sciences (BAS)	Bulgaria	
RE	Research Promotion Foundation (RPF)	Cyprus	
RE	Centre for Nuclear Technologies (DTU)	Denmark	
RE	University of Tartu	Estonia	
RE	Estonian Research Council	Estonia	
RE	VTT Technical Research Centre	Finland	
RE	The Federal Institute for Geosciences and Natural Resources (BGR)	Germany	
RE	National Technical University of Athens (NTUA)	Greece	
RE	Institute of Nuclear Technology & Radiation Protection at the National Centre of Scientific Research (INT-RP)	Greece	
RE	Budapest University of Technology and Economics (BME)	Hungary	
RE	Hungarian Academy of Sciences and Centre for Energy (MTA)	Hungary	
RE	National Agency for Energy and Research Innovation	Luxembourg	
RE	Geological Survey of the Netherlands	The Netherlands	
RE	Utrecht University Faculty of Geosciences	The Netherlands	
RE	Central Laboratory for Radiological Protection	Poland	
RE	Polish Geological Institute and National Research Institute	Poland	Yes
RE	Nuclear and Technological Campus (CTN), of the Instituto Superior Técnico (IST)	Spain	
RE	Centre for Energy, Environmental and Technological Research (CIEMAT)	Spain	Yes
RE	Technical University of Madrid (UPM)	Spain	
RE	The Engineering and Physical Sciences Research Council (EPSRC)	UK	
RE	The Natural Environment Research Council (NERC)	UK	
RE	VUJE	Slovakia	
RE	The State Geological Institute of Dionýz Štúr	Slovakia	

[18] Those in bold denote the organisations that JOPRAD Partners

RE	Slovenian National Building and Civil Engineering Institute	Slovenia	
RE	Geological Survey of Slovenia	Slovenia	
RE	Paul Scherrer Institute (PSI)	Switzerland	Yes
WMO	Nuclear Engineering Seibersdorf GmbH (NES)	Austria	
WMO	Radioactive Waste Management Directorate (RAWMD)	Bulgaria	
WMO	APO	Croatia	
WMO	**Radioactive Waste Repository Authority (Surao)**	**Czech Republic**	Yes
WMO	The Economy and the Ministry of Communications	Estonia	
WMO	**The National Radioactive Waste Management Agency (ANDRA)**	**France**	Yes
WMO	The Federal Office for Radiation Protection (BfS)	Germany	Yes
WMO	Greek Atomic Energy Commission (EEAE)	Greece	
WMO	Public Limited Company for Radioactive Waste Management (PURAM)	Hungary	Yes
WMO	State Enterprise Radioactive Waste Management Agency (RATA)	Lithuania	
WMO	Central Organisation for Radioactive Waste (COVRA)	The Netherlands	Yes
WMO	Polish Radioactive Waste Management Plant	Poland	
WMO	SOGIN	Italy	Yes
WMO	Latvian Environment, Geology and Meteorology Centre (LEGMC)	Latvia	
WMO	Technological Campus of Instituto Superior Técnico, University of Lisbon	Portugal	
WMO	National Agency for Radioactive Waste (ANDRAD)	Romania	
WMO	Nuclear and Decommissioning Company (JAVYS)	Slovakia	
WMO	Slovenian Agency for Radioactive Waste Management (ARAO)	Slovenia	Yes
WMO	National Cooperative for the Disposal of Radioactive Waste (Nagra)	Switzerland	Yes
WMO	Posiva Oy, Nculear Waste Management Organisation	Finland	Yes
WMO	Enresa Radioactive Waste Management Organisation	Spain	Yes
WMO	Swedish Nuclear Fuel and Waste Management Company (SKB)	Sweden	Yes
WMO	Ondraf/Niras, Belgium Radioactive Waste Management Organisation	Belgium	Yes
WMO	**Radioactive Waste Management Limited**	**UK**	Yes
TSO	Global Research for Safety (GRS)	Germany	Yes
TSO	DECOM	Slovakia	Yes
TSO	Institue 'Jožef Stefan'	Slovenia	
TSO	Centre for Physical Sciences and Technology (CPST)	Lithuania	Yes
TSO	TS Enercon Kft (TSE)	Hungary	Yes
TSO	NRG	The Netherlands	Yes
TSO	**Reseach Centre Rez (CVREZ)**	**Czech Republic**	Yes
TSO	**Institute for Radiation Protection and Nuclear Safety**	**France**	Yes
TSO	**Bel V, subsidary of the Federal Agency for Nuclear Control**	**Belgium**	Yes

Appendix 3: Overview of SRA Strategic Themes, Domains and Sub-Domains

The table below gives an overview of the SRA, including the strategic themes, domains and sub-domain titles.

The sub-domains that are in italic font and with a grey background denote those that have been classified as having low common interest in this SRA.

The sub-domains that are in blue have been classified as having a high level of common interest.

Strategic Theme 1: Building Understanding	
1.1 Inventory, Waste Form and Waste Characterisation	
1.1.1 Inventory Uncertainty	*1.1.6 Fourth generation (Gen (IV)) wastes*
1.1.2 Waste Characterisation Techniques	1.1.7 Chemotoxic Species
1.1.3 Non-mature and Problematic Waste Conditioning	1.1.8 Novel Radioactive Waste Treatment Techniques
1.1.4 Radionuclide Release from Wasteforms other than Spent Fuel	1.1.9 Spent- Fuel Evolution
1.1.5 Geopolymers	*1.1.10 Spent Fuel Fissile Content*
1.2 Waste Packages and Consequences of Storage	
1.2.1 Waste Package Interfaces	1.2.3 Alternative HLW/Spent Fuel Container Material Development
1.2.2 Impacts of Extended Storage on Waste Packages	1.2.4 Reworking of Damaged and Aged Waste Packages
1.3 Near-field and Engineered Barrier System	
1.3.1 Bentonite and other Clay Based Components	1.3.5 Metallic & Cementitious Chemical Perturbations
1.3.2 Microbial Influence on Gas Generation	1.3.6 Salt Backfill
1.3.3 Cementitious Component Behaviour	1.3.7 HLW/ILW Near-field Evolution
1.3.4 Low pH Cements	1.3.8 Co-Disposal Interactions
1.4 Gas Generation and Transport	
1.4.1 Gas Migration through the Excavated disturbed Zone/EBS and Far-Field	1.4.3 Gas Transients
1.4.2 Gas Generation Processes	1.4.4 Gas Reactivity
1.5 Radionuclide and Chemical Species Migration	
1.5.1 Chemical Thermodynamics	1.5.7 Temperature Influence on Radionuclide Migration
1.5.2 Sorption, Site Competition, Speciation and Transport	1.5.8 Colloid Influence on Radionuclide Migration
1.5.3 Incorporation of Radionuclides in Solid Phases	1.5.9 Redox Influence on Radionuclide Migration
1.5.4 Transport of Strongly Sorbing Radionuclides	1.5.10 Ligand-Influenced Transport Modelling
1.5.5 Effects of Microbial Perturbations on Radionuclide Migration	1.5.11 Transport of Volatile Radionuclides
1.5.6 Organic-Radionuclide Migration	
1.6 Geosphere	
1.6.1 Fracture Filling	*1.6.4 Rock Matrix Diffusion*
1.6.2 Geological Uncertainties	1.6.5 Site Descriptive Models
1.6.3 Groundwater Evolution	
Strategic Theme 2: Building Confidence	
2.1 Safety Case	
2.1.1 Pre-closure disturbances	*2.1.4 Dose Thresholds*
2.1.2 Assessment Methodologies	*2.1.5 Managing Deviations*

2.1.3 Uncertainty Treatment	2.1.6 Waste Acceptance Criteria
2.2 Post-closure Process modelling and upscaling	
2.2.1 THMC Evolution	2.2.4 Upscaling THMC Models
2.2.2 Performance of Plugs and Seals	2.2.5 Natural Analogues
2.2.3 Oxidative Transients	2.2.6 Biosphere Models
2.3 Numerical Tools	
2.3.1 Performance Assessment Tools	2.3.5 Upscaling in Support of Performance Assessment
2.3.2 Open-source Performance Assessment Code	2.3.6 Heterogeneity
2.3.3 Long-range Transport Models	2.3.7 Improved Computing
2.3.4 Multi-scale Reactive Transport Models	
2.4 Operational Safety	
2.4.1 Fire and Explosion Assessment	*2.4.4 Accident Management and Emergency Preparedness*
2.4.2 Flooding Risk Assessment	*2.4.5 Interim Storage Facility Safety*
2.4.3 Impacts of Operational Safety	
2.5 Practical Implementation	
2.5.1 Operational Monitoring Strategies	*2.5.5 Concept & Design Adaptation*
2.5.2 Monitoring Strategies for Closure and Post-closure	*2.5.6 Mock-up Experiments*
2.5.3 Monitoring Technologies	2.5.7 Industrialization
2.5.4 Retrievability	2.5.8 Engineering Asset Management
Strategic Theme 3: Integrated Knowledge Management System (IKMS)	
3.1 Site Uncertainty Treatment	3.9 Safety Case Guidelines, Management & Review
3.2 Site Evolution Models	*3.10 Disused Sealed Radioactive Sources*
3.3 Site Selection Process	*3.11 Pre-licensing Management*
3.4 Technical and Socio-political Siting Criteria	*3.12 Co-disposal Interactions*
3.5 Inventory Collation & Forecasting	*3.13 Radiation Protection Optimisation Principle*
3.6 Evolution of Waste Inventory	3.14 Information Management (NEA RepMet)
3.7 Link to Waste Producers/ Fuel Manufacturers	3.15 EU Research Infrastructure
3.8 Concept Adaptation and Optimisation	*3.16 EU DGR Curricular*
	3.17 Reversibility

Appendix 4: Changes in 'Level of Common Interest' to Sub-Domains

Based on the consultation comments, some of the sub-domains have had their 'Level of Common Interest' altered. The methodology for this was as follows:

1. Suggestions for changes to Level of Common Interest were collated from all consultation comments for all sub-domains;
2. If a sub-domain had 2 or more suggestions for changes to Level of Common Interest from separate organisations, then the additional votes were incorporated into Step 3, outlined above.

This resulted in the followings sub-domains increasing in their Level of Common Interest:

- Sub-domain 1.4.2 Microbial Influence on Gas Generation moved from a Medium Level of Common Interest to a High Level of Common Interest;
- Sub-domain 1.7.5 Site Descriptive Models moved from a Medium Level of Common Interest to a High Level of Common Interest;
- Sub-domain 2.2.2 Performance of Plugs and Seals moved from a Medium Level of Common Interest to a High Level of Common Interest;
Sub-domain 2.5.7 Backfill Industrialisation (now called 'Industrialisation) moved from a Low Level of Common Interest to a Medium Level of Common Interest.

The 'Consequences of Storage' sub-domain was combined with the 'Waste Packages' sub-domain to form new 'Waste Packages and Consequences of Storage' sub-domain. As a consequence, sub-domain 1.3.2 – Impacts of Extended Storage on Waste Packages has moved into this new sub-domain and sub-domain 1.3.1 – Re-working of Aged Waste has been combined with sub-domain 1.2.1 – Damaged and Re-working Packages.

In addition, there were multiple comments that suggested a re-calculation of the data based on the 4 Research Entities for France being combined into one response, rather than counting as separate responders (as shown in Table 1). When combining responses, the highest priority score was taken. This resulted in changes to the following sub-domains:

- Sub-domain 1.2.1 Damaged and Re-working Packages moved from a Low Level of Common Interest to a Medium Level of Common Interest;
- Sub-domain 1.4.6 Salt Backfill moved from a Low Level of Common Interest to a Medium Level of Common Interest;
- Sub-domain 1.7.5 Site Descriptive Models moved from a Medium Level of Common Interest to a High Level of Common Interest;
- Sub-domain 3.15 EU Research Infrastructure moved from a Medium Level of Common Interest to a High Level of Common Interest.

All of these changes have been incorporated into this document and are reflected in the domain overviews and sub-domain tables.

Appendix 5: Consultation Response – New Domains for Future Consideration in an EJP

New Domain 1: Disposal concepts for small amounts of radioactive waste

The costs associated with existing waste disposal technologies are not commensurate with the resources available in small national programs. Without a convincing solution for the long-term management of their wastes, small programs cannot deploy appropriate management strategies since the disposal concept is a decisive parameter for the selection of treatment and conditioning techniques enabling safe waste disposal. Furthermore, the time scale of construction, operation and closure of the disposal facility is essential for the determination of interim storage specifications where the radioactive waste will be stored prior to disposal. The cost for long-term storage is prohibitive and therefore the determination of a cost-effective and safe disposal solution in the next years is a necessity for small national programs.

The following sub-domain is currently identified:

New Domain 1.1 Borehole disposal concepts for small amounts of radioactive waste

<table>
<tr><th colspan="3">New Domain 1.1 Borehole disposal concepts for small amounts of radioactive waste</th></tr>
<tr><td rowspan="2">Background
The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management and the European Council Directive 2011/70/EURATOM require all Member States to establish a transparent and appropriate national program for the disposal of their radioactive waste.
A possible suitable option for small programs is the disposal in engineered fit-for-purpose boreholes, which offer the prospect of economic disposal on a small scale while meeting all the safety requirements. Concepts for the disposal of sealed sources in boreholes at depths of several tens of meters and the disposal of HLW in deep boreholes of 3 to 5 km are already investigated. The use of the borehole disposal concept for solid radioactive waste not being sealed sources at intermediate depths (i.e. hundred to a few thousands meters) is nor realized neither sufficiently investigated, but seems to be a cost-effective and safe solution for countries with low amounts of radioactive waste.</td><td colspan="2">Needs/Driver

To investigate the possibility for countries without nuclear power program to dispose of small amounts of radioactive waste in boreholes especially at intermediate depths.</td></tr>
<tr><td colspan="2">Objectives
Comparison of possible disposal options for countries with small amounts of radioactive waste (borehole disposal, near-surface disposal options, disposal in used mines, bunkers and tunnels, multi-regional disposal facilities, etc.),
Study of conceptual designs for the safe and cost-effective disposal of all types and classes of solid waste in intermediate depth boreholes,
Development and assessment of technologies to stabilize large diameter boreholes (1 to 3 m),
Development of technical requirements and technologies for the retrieval of waste packages from boreholes,
Development of an optimized safety barrier system,
Preliminary determination of waste acceptance criteria for the application of this disposal option,
Determination of requirements for the site,
Development of methodologies to assess the level of safety provided by the disposal system</td></tr>
<tr><td colspan="2">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="2">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="3">Organisations having expressed an interest in this domain:
BMLFUW (Austria), University of Cyprus (Cyprus), CV REZ (Czech Republic), EEAE (Greece), NCSR Demokritos (Greece), DMT (Germany), IST – LPSR (Portugal)</td></tr>
</table>

New Domain 2: Engineering Asset Management

A further sub-domain, 2.5.8 Engineering Asset Management, was added post-consultation based on a consensus view which agreed with consultation feedback that this was missing from the original domain scope.

<table>
<tr><th colspan="6">New Domain 1.2 Engineering Asset Management</th></tr>
<tr><td rowspan="2">Background
'Asset management' refers to the strategic plan, processes and actions that are needed to upkeep the 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.</td><td colspan="5">Research Needs/Driver
Nuclear waste deposition facilities will be operational over decades. During this time, a plenitude of maintenance activities and modernisation of assets (including equipment, machinery, infrastructure, real estate, data/computer systems, etc) are required. The requirements arising from the upkeep and improvement of the assets and a preliminary asset management strategy should be defined already in the design phase. Knowledge can be shared to less advanced programs based on international experience.</td></tr>
<tr><td colspan="5">Research Objectives
To develop concepts for cost-effective asset management strategies for a deposition facility.

To develop criteria for managing assets that balances risk, cost and benefit of the assets over their life cycles. Evaluate alternative scenarios for asset management approaches.</td></tr>
<tr><td colspan="5">Implementation Driven</td><td>✓</td></tr>
<tr><td colspan="5">Transfer of Knowledge to LAPs</td><td>✓</td></tr>
<tr><td colspan="6">Level of Common Interest – To be determined – provisional indicative score of Medium allocated.</td></tr>
<tr><td>High</td><td></td><td>Medium</td><td>✓</td><td>Low</td><td></td></tr>
</table>