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SITEX-II

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Strategic Research Agenda of the Expertise function in the field of geological disposal of radioactive waste

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SITEX-II OUTLINES

Sustainable network for Independent Technical EXpertise of Radioactive Waste Disposal – Interactions and Implementation (SITEX-II)

The coordination and support action SITEX-II was initiated in 2015 within the EC programme Horizon 2020 with a view to further developing the independent Expertise Function network in the field of deep geological disposal safety. This network is expected to ensure a sustainable capability for developing and coordinating, at the international level, joint and harmonized activities, related to the Expertise Function. SITEX-II brings together representatives from 18 organisations involving regulatory authorities, technical support organisations, research organisations, specialists in risk governance and interaction with general public, including NGOs and an education institute. It is aimed at practical implementation of the activities defined by the former EURATOM FP7 SITEX project (2012–2013), using the interaction modes identified by that project. SITEX-II, coordinated by IRSN, is implemented through 6 Work Packages (WP).

WP1 - Programming R&D (lead by Bel V). The general objective of WP1 is to further define the Expertise Function's R&D programme necessary to ensure independent scientific and technical capabilities for reviewing a safety case for geological disposal. In this perspective WP1 will develop a Strategic Research Agenda (SRA) and define the Terms of Reference (ToR) for its implementation accounting for the preparatory work to be carried out in the framework of the JOPRAD project for construction of a Joint Programming of research for geological disposal.

WP2 - Developing a joint review framework (lead by FANC). The key objective of WP2 is to further develop and document in position papers and technical guides a common understanding of the interpretation and proper implementation of safety requirements in the safety case for the six phases of facility development (conceptualization, siting, reference design, construction, operational, post-closure).

WP3 - Training and tutoring for reviewing the safety case (lead by LEI). WP3 aims to provide a practical demonstration of training services that may be provided by the foreseen SITEX network. A pilot training will focus on the development of training modules at a generalist level, with emphasis on the technical review of the safety case, based on national experiences, practices and prospective views. The training modules will integrate the outcomes from WP1, WP2 and WP4 and support harmonisation of the technical review processes across Europe.

WP4 - Interactions with Civil Society (lead by Mutadis). WP4 is devoted to the elaboration of the conditions and means for developing interactions with Civil Society (CS) in the framework of the foreseen SITEX network, in view of transparency of the decision-making process. The future SITEX network is expected to support development of these interactions at different levels of governance and at different steps of the decision-making process. Three thematic tasks, namely R&D, safety culture/review and governance will be addressed by institutional experts and representatives of CS within SITEX-II as well as externally through workshops with other CS organisations.

WP5 - Integration and dissemination of project results (lead by CV REZ). The overall objective of WP5 is to produce a synthesis of the results achieved within all the WPs of SITEX-II together with an Action Plan that will set out the content and practical modalities of the future Expertise Function network. WP5 will also foster the interactions of SITEX-II with external entities and projects, as well as the dissemination of SITEX-II results so as to allow possible considerations from outside the project in the process of developing the future SITEX network.

WP6 - Management and coordination (lead by IRSN).

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Further details on the SITEX-II project and its outcomes are available at **www.sitexproject.eu**

ABSTRACT

The independence of the regulatory function calls for the support of an independent expertise function that develops and maintains the necessary know-how and skills in the field of nuclear safety. For complex issues such as those associated with the operational and long-term safety of waste disposal facilities, this can be achieved by performing and/or overseeing R&D in support of safety analyses and “horizontal” activities such as exchanging on practices, establishing states of the art and transferring knowledge. R&D and horizontal activities performed by the expertise function are also an important contributor to the development of its technical expertise and necessary to build the credibility of its technical competences (e.g. vis-a-vis the Civil Society), integrity and judgement. In this context, this document presents the Strategic Research Agenda (SRA) of the SITEX initiative (Sustainable network for Independent technical expertise of radioactive waste disposal).

The general objective of the SITEX initiative is to meet the vision of fostering at the international level a high quality and independent expertise in the safety of geological disposal (GD) of radioactive waste. The objective of the SRA produced by SITEX-II is to identify and prioritise the needs for competence and skills development of the expertise function, at the international and in particular at the European level, based on a transparent methodology and taking into consideration the different states of advancement of GD programmes and the concerns of the Civil Society (CS). The scope of the SRA covers all the topics relevant to the expertise function 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.

After an introduction to the context of the development of the SRA and, more particularly, to the link between the EC H2020 JOPRAD and SITEX-II projects, this deliverable presents the scope and objectives of the SRA, as well as its contributors and the advancement state of their national GD programmes. Then, the methodology followed to identify the topics in which a common interest of SITEX-II WP1 partners exists for research activities as well as horizontal activities is described, as well as the outcomes of the application of this methodology. A common interest exists for undertaking activities in the following key topics: waste inventory and source term, transient THMBC conditions in the near-field, evolution of EBS material properties, radionuclide behaviour in disturbed EBS and HR, safety-relevant operational aspects, managing uncertainties and the safety assessment, as well as lifecycle of a disposal programme and its safety case. For each key topic, a justification of its importance to safety is given and specific issues of common interest are identified. Afterwards, conditions for implementing R&D on these key topics in the framework of a joint programming are discussed. Finally, the main concerns of representatives of the CS considered in this SRA are summarized.

CONTENT

List of abbreviations:

CS: civil society
DGR: deep geological repository
EBS: engineered barrier system
EC: European commission
GD: geological disposal
HLW: high level waste
HR: host rock
ILW: intermediate level waste
JP: joint programming
LLW: low level waste
MBS: multi barrier system
NRA: national regulatory authority
QA: quality assurance
QC: quality control
R&D: research and development
RB: regulatory body
RE: research entity
RN: radionuclide
RWM: radioactive waste management
SC: safety case
SF: spent nuclear fuel
SRA: strategic research agenda
SSC: systems, structures and components
THMBC: thermo, hydro, mechanical, biological and chemical
TSO: technical support organisation
WAC: waste acceptance criteria
WMO: waste management organisation

1 Introduction

1.1 CONTEXT

The European Commission Communication of December 2011 “Energy Roadmap 2050” recognises the important contribution of nuclear energy in Europe today: approximately 30% of electricity generation (produced by 131 reactors in 14 EU countries), representing over 60% of the low-carbon energy sources in Europe. Nuclear safety is a prime consideration in Europe but the Fukushima accident has increased public concern over nuclear energy, drawing renewed attention to the safety of nuclear power plants and other nuclear fuel cycle facilities.

With a view to ensuring that safe solutions for the management of spent nuclear fuel and radioactive waste will be available, the EU has both set down safety legislation and established collaborative programmes of research and development. In 2011 Council Directive 2011/70/Euratom of 19 July 2011 was promulgated, establishing a Community Framework for the Responsible and Safe Management of Spent Fuel and Radioactive Waste, in 2014 a Council Directive amending Directive 2009/71/Euratom established a Community Framework for the safety of nuclear installations, and finally the Council Directive 2013/59/Euratom of 5 December 2013 updated the basic safety standards for protection against exposure to ionising radiation.

The H2020 EURATOM Work Programme 2014-2015 involves a number of activities concerning nuclear fission and radiation protection including a topic grouping those that “Contribute to the Development of Solutions for the Management of Ultimate Radioactive Waste” and in particular the SITEX-II and the JOPRAD projects. A key objective of the SITEX-II project (“Sustainable network for Independent Technical EXpertise of radioactive waste disposal - Interactions and Implementation”) is to consolidate at the international level the knowledge base and expertise upon which organisations fulfilling an expertise function[1] in the context of the licensing process of underground radioactive waste disposal facilities can rely on, and to stimulate its sharing amongst all stakeholders, including Civil Society (CS).

In the context of geological disposal, the mission of the expertise function is to support the regulatory function as illustrated in Figure 1 [1] by ensuring that the disposal facility is developed, constructed, operated and closed in a safe manner, without imposing undue burdens on future generations i.e. people and the environment are protected against the hazards of ionising radiations emitted by the disposed radioactive waste. This mission involves several types of activities, such as participating in the establishment of regulatory requirements, as well as the development of guidance for meeting these requirements at the different stages of the licensing process. The mission of the expertise function includes

[1] The expertise function provides the technical and scientific basis notably for supporting the decisions made by the regulatory function.

also the review of the Safety Case (SC) and of its updates throughout the whole process of developing and implementing the geological disposal programme.

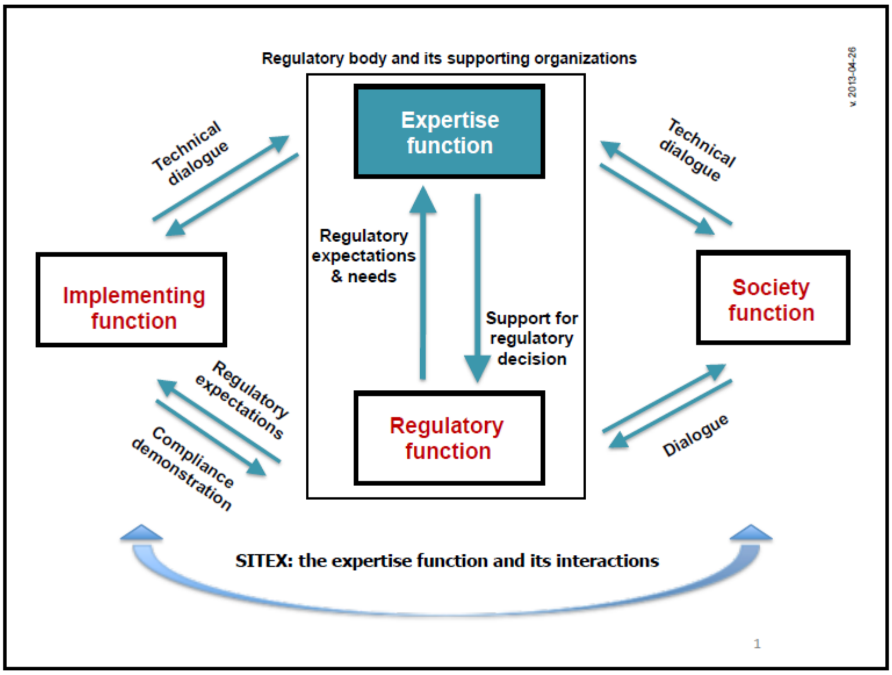

Figure 1: the expertise function and its interactions (figure issued by the former SITEX project [1])

The review of a SC aims to determine whether it has been developed to an acceptable level in terms of quality and provides sufficient confidence in safety to move to the next phase of the disposal programme. With this objective in mind, the expertise function has to verify that the SC demonstrates compliance with the safety requirements. The expertise function has to evaluate whether the SC provides an adequate and appropriate basis to demonstrate that the proposed facility will be operated safely and provides reasonable assurance of an adequate level of safety in the post-closure period. The expertise function has also to verify that relevant measures for managing uncertainties have been identified and addressed, and that adequate follow-up plans for their implementation (e.g. via R&D programmes) have been developed. More specifically, the review of a SC aims notably at assessing the following aspects:

- the proper justification of the methods used to obtain data and the confidence in the data;
- the understanding of the processes that govern the performance of the Systems, Structures and Components (SSC) of the disposal facility and their ability to fulfil their assigned safety functions;
- the evaluation of the long-term evolution of the disposal system, taking into account the influence of the uncertainties on the different potential evolutions of the system;
- the due consideration of potential hazards that could impair safe operation of the

disposal facility, including the influence of accidents and extreme natural events during the operational phase on the operational safety and on the long-term safety.

As stated by article 6-2 of the EC Directive 2011/70/Euratom of 19 July 2011, the regulatory function has to be independent of the implementing function fulfilled by Waste Management Organizations (WMOs):

> *"Member States shall ensure that the competent regulatory authority is functionally separate from any other body or organisation concerned with the promotion or exploitation of nuclear energy or radioactive material, in order to ensure effective independence from undue influence in its regulatory function"*.

Accordingly, the independence of the regulatory function calls for the support of an independent expertise function that develops and maintains the necessary know-how and skills in the field of nuclear safety. For complex issues such as those associated with the operational and long-term safety of waste disposal facilities, this can be achieved by performing and/or overseeing R&D in support of safety analyses and horizontal activities such as exchanging on practices, establishing states of the art and transferring knowledge. R&D and horizontal activities performed by the expertise function are also an important contributor to the development of its technical expertise and necessary to build the credibility of its technical competences (e.g. vis-a-vis the Civil Society), integrity and judgement.

This need for R&D and horizontal activities by the expertise function is identified in international recommendations and requirements. For instance, the 2011/70/EURATOM directive requires the expertise function to carry out its own horizontal and R&D activities:

> *"Article 8 - Expertise and skills - Member States shall ensure that the national framework require <u>all parties</u> 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."*

It is also stressed in IAEA safety guides that the Regulatory Body (RB), and thus its supporting organisations (see figure 1), may need to conduct or commission R&D in support of regulatory decisions.

> IAEA GS-G-1.1 [2] (see §3.33)
>
> *"There may be situations in which the operator's research and development are insufficient or in which the regulatory body requires independent research and development to confirm specific important findings. The regulatory body may need to conduct or commission research and development work in support of its regulatory functions in such areas as inspection techniques and analytical methods or in developing new regulations and guides."*
>
> IAEA GS-G-1.2 [3] (see §3.68)
>
> *"The regulatory body may decide to initiate research and development work where it considers that there is a need for additional studies beyond those undertaken by the*

operator. There may also be situations in which the regulatory body requires independent research and development work so that it can apply suitable critical considerations in its review and assessment."

It is important to highlight that the expertise function's R&D objectives may differ from those adopted by the WMOs. For instance, the expertise function's R&D is mostly intended to investigate safety issues with the objective to assess if the safety concept developed by the WMO fulfils the defined safety requirements. In that way, a special attention is given to the identification of questionable assumptions, knowledge gaps and incompleteness in the safety assessment performed by the WMO. These "challenging" activities are therefore more a "complement to" and "a verification of" than a "duplication of" the R&D activities performed by the WMO. This being said, a type of activity could be challenging at a given time, and could later be integrated e.g. in a WMO's R&D programme or in a European Joint Programming (and thus would not be anymore a "challenging" activity).

1.2 THE SITEX-II AND JOPRAD PROJECTS

The SITEX-II project gathers National Regulatory Authorities (NRAs), Technical Support Organisations (TSOs) and Research Entities (REs) fulfilling an expertise function, as well as organisations representing the Civil Society (CS). Its overall objective is the practical implementation of the sets of activities and interaction modes issued by the former EC FP7 SITEX project (2012-2013) [1], with a view to develop at the European and international level an expertise function network. This network is expected to ensure a sustainable capability to develop and coordinate joint and harmonized activities related to the independent technical expertise function in the field of safety of geological disposal of radioactive waste. The followings tasks are carried out within the SITEX-II project:

- The definition of a Strategic Research Agenda (SRA) of the expertise function, taking into consideration the concerns of the CS;
- The production of guidance on the technical review of the safety case;
- The development of a training module for generalist experts involved in the safety case review process;
- The preparation of the administrative framework for a sustainable network, by addressing the legal, organisational and management aspects.

The SITEX-II project is also meant to provide an input to the JOPRAD project [4] ("Towards a Joint Programming Project on Radioactive Waste Disposal").More particularly, task 3.2 of the JOPRAD project aims notably at identifying activities of the SITEX-II SRA that could be achieved within the framework of a Joint Programming (JP). In practice, SITEX-II WP1 sent a draft version of the SRA and the identified boundary conditions (see §8) to JOPRAD six months after the start of the project (T0+6 months). The SITEX-II SRA was then used as a starting point in the TSO working group of JOPRAD to establish the potential topics for which Joint Programming (JP) activities could be developed together with WMOs and/or REs.

The overall aims of the JOPRAD project (Coordination and Support Action "Towards a Joint Programming on Radioactive Waste Disposal") are to assess the feasibility and, if appropriate, to generate a proposal for Joint Programming in the field of Radioactive Waste Management, including geological disposal. This proposal is built for implementation in a future EURATOM Work Programme. Joint Programming includes Research, Development and Demonstration (RD&D) activities, with the accompanying Knowledge Management Programme and its horizontal activities, namely establishing a state-of-the-knowledge handbook coupled with education, training, strategic studies, guidance, transfer of knowledge to less advanced programmes, as well as dissemination.

The main outcomes of the JOPRAD project will be a set of documents addressing RD&D key priorities of nationally mandated actors including waste management organisations (WMOs), technical support organisations (TSOs), and research entities (REs). In addition there will be a programme for knowledge management, including the above listed horizontal activities, as well as a proposal for governance and financing structure for the implementation of a Joint Programme. In addition, it is also intended for Civil Society stakeholders to bring in their interests and ways to be involved in the different activities, as well as participation in the Governance.

2 Objective of the SRA, underlying vision and commitments

The general objective of the SITEX initiative is to meet the vision of fostering at the international level a high quality and independent expertise in the safety of geological disposal of radioactive waste. The objective of the SRA produced by SITEX-II is to identify and prioritise the needs for competence and skills development of the expertise function, at the international and in particular at the European level. These needs include research activities as well as horizontal activities such as exchanging on practices, establishing states of the art and transferring knowledge.

The commitments of the SITEX-II members for the development of the SRA are the following:

- The SRA is developed by applying **a transparent methodology that appropriately considers available information, uses well-supported analysis methods, and is implemented by independent experts**;
- The SRA addresses the needs associated with **the different states of advancement** of GD programmes;
- The concerns of Civil Society **are taken into consideration**.

3 Scope of the SRA

The scope of the SRA covers all the topics relevant to the expertise function 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. The scope encompasses all topics relevant to any waste type and spent fuel for which geological disposal is envisaged as a solution for its long-term management. Actions dedicated to pre-treatment, treatment, conditioning, as well as transport and storage of radioactive waste having an impact on the safety of geological disposal facilities could also be considered in the SRA. Furthermore, activities related to management options other than geological disposal may be addressed by the SITEX network if relevant to several national programmes. However, this first version of the SRA is specifically focused on disposal in underground facilities.

In addition to R&D activities, the needs for knowledge transfer (e.g. training or tutoring), for developing state of the art and for exchanging on practices and developing common positions are also identified in the SRA.

The current SRA is not an exhaustive list of all the potential topics that could enter into the scope above. It covers topics for which a sufficient level of common interest has been expressed amongst the SITEX-II members (see section 5 for the applied methodology).

4 Contributors to the SRA and the national GD programmes and concepts

4.1 ORGANISATIONS CONTRIBUTING TO THE DEVELOPMENT OF THE SRA

This SRA was developed within the SITEX-II Work Package 1 (WP1, “Programming R&D”), in which the following organizations fulfilling an expertise function participate:

- Bel V, Belgium
- Federal Agency for Nuclear Control, FANC, Belgium
- Geological Institute of Bulgarian Academy of Sciences, GI-BAS, Bulgaria
- Canadian Nuclear Safety Commission CNSC, Canada
- Centrum výzkumu Řež s.r.o., CVREZ, Czech Republic
- Institut de Radioprotection et de Sûreté Nucléaire, IRSN, France
- Gesellschaft für Anlagen-und-Reaktorsicherheit, GRS, Germany
- Lietuvos Energetikos Institutas, LEI, Lithuania
- Paul Scherrer Institut, PSI, Switzerland

The CS function (see figure 1) represented by MUTADIS and MKG (Swedish NGO Office for

Nuclear Waste Review) was also involved in the process, as described below in section 5.1. The SRA was reviewed by the Associated Group members of SITEX-II and by all the SITEX-II partners.

4.2 ADVANCEMENT STATE OF NATIONAL PROGRAMMES

The EPG report [5] on the regulatory review of a Safety Case for a geological disposal facility defines the following 6 key phases of disposal programme development:

(1) The **conceptualisation phase**, during which an implementer considers potential sites and design options, establishes the safety strategy and carries out preliminary assessments. Regulatory review of the work at this phase should guide the implementer on the likelihood of achieving the necessary demonstration of safety and should help the implementer decide whether to commit resources to move to the next phase of the project.

(2) The **siting phase**, during which the implementer identifies potentially suitable sites that are compatible with the concept in terms of the adopted safety strategy and characterizes these sites based on a preliminary safety case to the extent that a decision can be made on the preferred site.

(3) The **reference design (and application for construction) phase**, during which the implementer adapts the conceptual design to the site properties, finalises and validates the design of the disposal facility, and develops the safety case, to support his application to construct, operate and close the facility. This is used by the regulator to decide whether to grant a licence for the implementer to construct the facility and this phase is a crucial milestone in the development of a disposal facility.

(4) The **construction (and application for operation) phase**, during which the implementer demonstrates that it is safely constructing the disposal facility and that it has built the facility as planned and in accordance with the terms of the construction licence. Towards the end of this phase, the implementer will present its final overall approach for operation and a draft concept for closing the facility. In preparing for operation, the implementer will need to demonstrate safety during operation and radiation protection of workers and members of the public and the environment. The regulator would typically decide whether to grant a separate licence or approval before emplacement of waste in the facility would start. It should be noted that construction activities are generally expected to be carried on beyond the construction phase (i.e. during the operational phase).

(5) The **operational phase**, during which the implementer emplaces waste packages and closes the disposal facility. During this phase, the implementer may build new disposal units, and backfill and possibly seal, either temporarily or permanently, parts of the disposal facility where waste emplacement has been completed. The implementer also develops an application to close (decommission) and seal the facility, and further develops the plan for post-closure institutional controls,

monitoring and surveillance. The regulator will decide during this phase whether to grant a licence for the implementer to close (decommission) and seal the facility. When the licence is granted, the implementer proceeds to the closure of the facility.

(6) The **post-closure phase**, at the start of which the implementer provides evidence to demonstrate that it has closed (decommissioned) the disposal facility in accordance with safety requirements and presents a firm plan for institutional controls and continuing monitoring and surveillance. At this phase, the regulatory body will confirm what controls, monitoring and surveillance are required and for how long. Compared to "pre-closure" phases during which post-closure safety has to be thoroughly taken into consideration, the amount of activities carried out during this phase is expected to decrease significantly. The expected duration of these controls is country-specific. Indeed, the discussions in the SITEX WP2 ("Regulatory expectations and needs") [6] have emphasised that the activities that would be performed during the post-closure phase are strongly sensitive to the national specificities. For instance, the nature of the controls that would be performed during this phase and their expected duration may differ from one country to another. The technical support activities that may be needed during the post-closure phase may therefore differ from one country to another.

In the deliverable D2.2 of the EC FP7 SITEX project [6], Figure 2 was developed linking these 6 phases to the pre-licensing, licensing and post-closure periods.

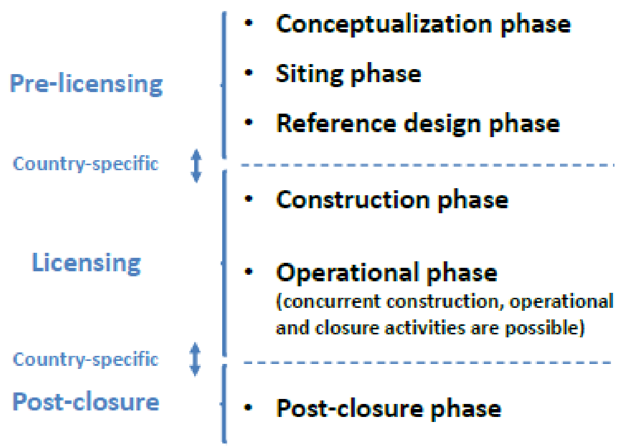

Figure 2: Key phases of geological disposal programme development and relationships with the pre-licensing, licensing and post-closure periods. [6]

Table 1 gives an overview of the current disposal programme development phase in the participating countries.

Table 1: Current geological disposal programme development phase in participating countries.

	(1)Conceptualization	(2) Siting	(3) Reference design	(4) Construction	(5) Operation	(6) Post-Closure
Belgium	X					
Bulgaria	X					
Canada		X (spent fuel disposal facility)	X (Pending decision of the EA for low and intermediate level waste (L&ILW))			
Czech Republic		X				
France			X High-Level Waste (HLW) and Long-Lived Intermediate-Level Waste (LL-ILW)			
Germany	X HLW and SNF disposal facility			X KONRAD disposal facility (ILW, LLW)	X (Closure phase) ERAM disposal facility (ILW, LLW)	
Lithuania	X					
Switzerland		X				

4.3 GEOLOGICAL DISPOSAL FACILITY CONCEPTS

As shown in Table 2, a variety of geological disposal concepts are considered but they all have some common features. All concepts are developed to confine and isolate the waste from man and the environment. Geological disposal facilities are designed to be passively safe after closure. As a result of the application of the defence in depth principle, geological disposal facility concepts are notably based on the multi-barriers/multi-functions principle whereby the long-term safety is ensured by the geological barrier(s) and the Engineered Barrier System (EBS) that act in tandem. The following disposal system components typically contribute to long-term safety by fulfilling one or several safety function(s):

- waste form;
- waste container and its possible overpack;
- other engineered barriers (e.g. seals, backfills…);
- geological barrier(s).

These engineered and natural barriers will hinder the migration of radionuclides to the biosphere (e.g. by relying on the favourable hydraulic and chemical characteristics of the host rock and/or of engineered materials such as steel, concrete, bentonite and others). This slow migration rate is required to allow for a sufficient inventory depletion through radioactive decay before the radionuclides reach the accessible biosphere, and therefore contribute to the long-term safety of the disposal facility. The geological barriers also play a key role in isolating the waste from the accessible biosphere and in reducing substantially the likelihood of, and all possible consequences of inadvertent human intrusion into the facility. They provide a stable physical and chemical environment for the engineered barriers within the disposal facility, and protect them against external perturbations such as earthquakes and climate change.

Table 2: Geological disposal facility concepts considered in the national programmes of SITEX-II WP1 participants

	disposal system components currently considered in the national programmes				Reversibility & Retrievability
	Waste forms and/or spent fuel	**Waste containers**	**Surrounding EBS**	**Host rock(s)**	
Belgium[2]	SF, vitrified HLW and ILW (unconditioned or conditioned e.g. in cement or bitumen)	HLW/SF: Supercontainer (carbon steel overpack with concrete buffer) LL-I/LLW: concrete monoliths	Cement-based backfill. Bentonite seal, concrete seal or a combination of both	Poorly indurated clay formations (Boom and Ypresian Clays)	According to the law, reversibility and retrievability will have to be considered
Bulgaria	SF –direct disposal and/or as vitrified HLW HLW - conditioned	not defined; two options are considered: - direct disposal in steel supercontainers; - conditioned HLW in canisters	Not defined	Options based on the preliminary selection of potential sites/host rocks: - Lower Cretaceous	According to the current legislation, the reversibility and retrievability has to be considered during the operational

[2] There is currently no national policy and hence national programme for the long term management of SF, HLW and ILW in Belgium. The concept presented in this table is the reference option developed and investigated by ONDRAF/NIRAS (WMO).

	disposal system components currently considered in the national programmes				Reversibility & Retrievability
	Waste forms and/or spent fuel	Waste containers	Surrounding EBS	Host rock(s)	
		and after that in steel containers		clayey marl formations; - Neogene (Miocene) clay formation	phase
Canada	SNF or used nuclear fuel, and, L&ILW, conditioned or unconditioned (clothing, tools, equipment, heat exchangers; ion exchange resins, filters, and irradiated reactor core components etc.)	L&ILW: Carbon steel and stainless steel container and overpack, concrete shield. SNF: Carbon steel inner vessel with copper outer shell, or, Carbon steel vessel with copper coating.	L&ILW: concrete, bentonite and sand mixture, and bitumen for shaft backfill SNF: Bentonite and bentonite based seal/buffer	L&ILW: Argillaceous limestone, SNF: reference options: either granite rock or sedimentary rock (to be decided)	Not a legal requirement.
Czech Republic	SNF and HLW direct disposal, small amount of vitrified SNF from research reactors	Steel container, supercontainer under discussion	Bentonite seal	Granitic and metamorphic rocks	Not required for Czech Republic
Switzerland	SNF, vitrified HLW, ILW and LLW	LLW/ILW: steel drums with cementitious waste matrix, different cement containers HLW: Copper coated carbon steel containers	L&ILW: concrete, bentonite and sand mixture HLW: Bentonite and bentonite based seal/buffer	Opalinus Clay and adjacent layers (HLW/ILW/LLW) / Wellenberg Marl (LLW)	According to the law, reversibility (including retrievability) has to be considered (incl. pilot disposal facility with monitoring phase)

	disposal system components currently considered in the national programmes				Reversibility & Retrievability
	Waste forms and/or spent fuel	Waste containers	Surrounding EBS	Host rock(s)	
France	Vitrified HLW and LL-ILW (conditioned mainly in cement, bitumen)	HLW: carbon steel overpack ILW: concrete monoliths	HLW: carbon steel liner and plugs (bentonite + concrete) ILW: cement-based backfill Bentonite seal between concrete components in drifts and ramp & shafts + clayey backfill	Indurated clay formation (Callovo-Oxfordian Clays)	According to the law, reversibility (including retrievability) has to be considered
Lithuania	RBMK-1500 SNF, long lived LILW (unconditioned or conditioned)	Only proposals, not defined in national program/law: For SNF in clay: steel canister For SNF in crystalline rocks: Copper canister For long-lived LILW: Metal container with cementitious encapsulant	Only proposals, not defined in national program/law For SNF: bentonite buffer For long-lived LILW: cementitious tunnel backfill	Potential formations: Triassic clay, Cambrian Clay, Crystalline rocks	Not defined in law

	disposal system components currently considered in the national programmes				Reversibility & Retrievability
	Waste forms and/or spent fuel	**Waste containers**	**Surrounding EBS**	**Host rock(s)**	
Germany	SF, vitrified HLW, ILW and LLW	SF/HLW: CASTOR and POLLUX (but the final cask concept for the disposal is not defined yet, since this depends which site/host rock will be selected for the disposal system. ILW: Different container types of concrete and cast iron. LLW: Steel drums, different containers with concrete and iron cast.	SF/HLW: Salt, clay or bentonite depending of the host rock The current concept for shaft seals, drift seals and borehole plugs include a multi component structure with different materials. ILW (KONRAD): Shotcrete, complete backfill of excavations with mineral materials, shaft seals include different components with different materials. LLW (ERAM): Salt concrete. Seals include different components with different materials.	SF/HLW: Salt, clay and granite are potential host rocks. ILW (KONRAD): Former iron ore mine: ferreous layers and clay cover. LLW (ERAM): Former salt mine: salt.	SF/HLW: According to the safety requirements, retrievability for the disposal casks must be possible in the operational phase until the closure of the shafts or ramps. ILW (KONRAD) not intended LLW (ERAM): not intended

5 Methodology of SRA development

5.1 GENERAL METHODOLOGY

First step: identification of possible topics

The first step of the methodology involves developing a list of possible topics that could be of interest for the expertise function. In practice, a preliminary list of possible topics is developed (notably based on the deliverable D3.1 "R&D orientations for TSOs" of the former SITEX project [7]) and submitted to WP1 ("Programming R&D") partners who have the opportunity, whenever necessary, to complement this preliminary list.

Leaders of the SITEX-II WP4 "Interaction with CS" and its Task 1 "CS interacting with R&D", MUTADIS and MKG, respectively, are WP1 partners. In the framework of SITEX-II WP4 Task 1, MUTADIS and MKG interact with representatives of the CS in order to provide an input accounting for the concerns of the CS. In this framework a review of deliverable D3.1 of SITEX [7] was performed by WP4. The input of WP4 is discussed inside WP1. Suggested topics could be added to the WP1 list of possible topics if there is an agreement inside WP1. The main inputs of WP4 to the SITEX-II SRA are given in section 8 of this SRA.

Second step: appraisal of the common level of interest for the possible topics

For each topic of the list developed in step 1, each WP1 partner fulfilling an expertise function fills the following information in a questionnaire (see Appendix 1).

- The types of common activities in which they are interested for this topic. These activities could be: (activity type 1) new R&D projects (experiments and/or modelling work) or (activity type 2) other activities aiming at sharing, exchanging or consolidating knowledge and expertise, such as exchanging on practices inside working groups, or (activity type 3) developing states of the art or (activity type 4) transfer knowledge between organizations. These 3 last activity types are identified as "horizontal activities".
- Their level of interest ("H" for High, "M" for Medium or "N" for Not Interested) for such activities, along with a short justification and, if interested, partners are encouraged to provide a list of specific issues for which actions could be undertaken.

The choice between High, Medium and Not Interested levels of interest is made considering:

- The relevance of the topic to the geological disposal concept currently considered in its national programme;
- The gap between the need for knowledge/expertise of the partner in the topic and the current partner level of knowledge/expertise;
- The resources that the partner would allocate to the topic in the prospect of

carrying out joint actions.

For each topic, a first assessment of the common level of interest of WP1 partners representing the expertise function was carried out for the 4 possible joint activity types mentioned above, using the following criteria:

- Topics in which the expertise function has a high level of common interest: the level of interest is H for at least 3 WP1 partners representing the expertise function.
- Topics in which the expertise function has a medium level of common interest: 1H & 2M, 2H & 1M or 3M among WP1 partners representing the expertise function.
- Topics in which the expertise function has a low level of common interest: all the topics that do not meet the above criteria.

Third step: identification of the main topics and specific issues that will be included in the SRA

The preliminary list of topics obtained in step 2 for the 4 possible kinds of joint activities in which a high level of common interest could exist was discussed by WP1 with the following objectives:

- Verify that WP1 partners have the same understanding of these topics. If the partners' understanding of a topic differs, the topic is clarified and partners may decide to change their level of interest. In this case, the common level of interest is reappraised following the criteria described in step 2.
- Structure these topics into main topics of the SRA. A main topic can combine several topics, possibly associated to different kind of activity type.
- For each main topic, identify a list of specific issues in which there is a common interest. The first list of specific issues from step 2 is used to initiate the discussions.
- Address, for each identified main topic, the following points:
  - Why the topic is important to safety (e.g. it has been shown in existing safety cases)?
  - Why is research needed (e.g. lack of knowledge)?
  - Why is the topic a candidate for joint research (e.g. it is common to all disposal systems, findings are transposable, high cost)?
  - Is it a candidate for autonomous expertise function research (i.e. separate from other actors, e.g. because of high importance to safety and controversy over understanding, anomalous findings)?

Finally, the preliminary list of topics in which a medium level of common interest could exist for R&D (activity type 1) is discussed by WP1. If the specific issues associated to these topics are not already covered by the discussion about the topics with a high level of common interest, WP1 could decide to add them into the SRA (by adding new specific issues to the existing main topics or by defining new main topics). This consolidation step for the topics with a medium level of common interest is not applied to topics associated with activity types 2, 3 and 4. This step could be achieved later within SITEX-II in collaboration with WP2 ("Developing a joint review framework") and 3 ("Training and tutoring for reviewing the safety case"), i.e. to have a better overview of the needs for training and tutoring (WP3) and developing guidance and/or common positions relevant for establishing a joint review framework (WP2).

5.2 METHODOLOGY FOR UPDATING THE SRA

The SRA will be updated on a regular basis to take future developments and needs into consideration. The update methodology will have to be included into the terms of reference of the SITEX network. A possible mechanism could be to ask every 2 years to the partners involved into this network to provide a contribution to steps 1 and 2 with revised or new topics and level of interest. The impact of this input on the SRA content could then be consolidated by all the partners, based on step 3 of the SRA methodology.

6 SRA Main topics and associated specific issues

Based on the methodology presented in section 5, 7 main topics associated to specific issues and activities are included into the SRA. In Appendix 2, a table summarizes the main topics, issues and activities of common interest. The applied methodology allowed to consider the concerns of the CS about the R&D needs of the expertise function. It came out essential to consider the integration of Social and Citizen Science aspects in any new research projects or horizontal activities that will be launched in the future based on this SRA. Such Social and Citizen Sciences aspects were identified by WP4 and are synthetized in section 8. In the future, for each new project or activity based on the SRA, the expertise function will check with CS representatives which of these Social and Citizen Science aspects could be relevant and how to integrate them to the technical aspects that have to be investigated. This will result in "complex" (multidisciplinary) projects or activities, in which both technical and societal aspects will be investigated in an integrated manner, using specific interdisciplinary methodologies and involving CS participation. Examples of topics that could give rise to such "complex" (multidisciplinary) projects or activities are given in main topic 7.

6.1 MAIN TOPIC 1: WASTE INVENTORY AND SOURCE TERM

Importance of the main topic to safety

The inventory of radionuclides denotes the spectrum and activity of radionuclides in the waste forms to be disposed of. The potential for the release of particular radionuclides from this inventory out of the waste forms will be affected by the physical and chemical characteristics of the waste forms and the conditions in their surrounding medium (so called "near-field" of the disposal facility). The mathematical expression of this potential is known as the source term. It may denote the rate, chemical speciation and pathways for the release of the radionuclides out of the waste form. The characterization of the waste inventory and the understanding of the processes governing the source term are fundamental inputs to the safety assessment of a disposal system.

Rationale for developing joint activities

The waste to be disposed of in different countries will be similar. It could notably encompass any of the following categories of waste: spent nuclear fuel and/or high level waste from its reprocessing, intermediate level waste from reactor operation and decommissioning, high activity and long lived sealed sources and institutional waste. Therefore, international cooperation and coordination in developing a better understanding of the processes governing the source terms, as well as its use in the safety assessment is justified.

Research and/or horizontal activities of common interest

Source terms associated to cemented and vitrified waste, as well as spent fuel will be affected among others by the waste form composition and the conditions in the disposal facility. A reliable prediction of waste form degradation mechanisms, leaching rates of various radionuclides, radionuclide speciations, etc., thus requires systematic broad research. Several EC projects were already dedicated to this field of research (e.g. MICADO [8], FIRST NUCLIDES [9] , NF-PRO [10]). There is nevertheless a common interest for pursuing the R&D efforts in this field (see issue #3 in Table 3). Examples of specific issues of interest are:

- Impact of radiation on cement matrix transport properties, which is not included in WMO's R&D program regarding transport properties (challenging R&D by the expertise function), as far as we know;
- Impact of an alkaline environment (cement) on glass leaching;
- Evaluation of long term instant release fraction (IRF) for SF
- Investigation of unconventional spent fuel dissolution (e.g. MOX fuel and RBMK fuel) and chemistry under disposal conditions
- Influence of organic matter potentially present in concrete waste forms on radionuclide source term.

Table 3: Main Topic 1 (Waste inventory and source term) issues and activities of common interest

SRA Main Topics and associated issues		Research activities (experiment and/or modelling works)	Horizontal activities		
			Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring…)
Main Topic 1: Waste inventory and source term					
#1.	Uncertainty about databases and methodologies used for defining waste inventories (including historical waste)		■		
#2.	Evolution of the waste inventory due to possible neutron activation		■		
#3.	Understanding of the release processes and speciation of the radionuclides for different types of wastes	■	■	■	■
#4.	Waste acceptance criteria		■		■

Besides the need for R&D activities, there is a common interest in organizing horizontal activities on the methodologies applied to define the radionuclide inventories (e.g. use of radionuclide vectors, uncertainties about databases of radionuclide properties), to characterise the waste forms and to define the waste acceptance criteria (WAC), as well as the verification of the conformity to them (see issues #1 and 4 in Table 3). Such horizontal activities should take due account of ongoing international projects such as the IAEA project “Status and trends” [11] or the NEA expert group on inventorying and reporting methodologies (EGIRM) [12]. Exchanges on new treatments and conditioning, such as thermal processes and new mineral matrix other than usual concrete (e.g. geopolymer), are also foreseen. Moreover, the existing knowledge related to release processes and WAC is identified as candidate for transfer of knowledge, notably towards less advanced programmes. All these issues are of common interest for the expertise function as they could have a strong impact on the source term and related uncertainties associated with operational and long term safety assessments. 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 (see issues #2 in Table 3).

6.2 MAIN TOPIC 2: TRANSIENT THMBC CONDITIONS IN THE NEAR-FIELD

Importance of the main topic to safety

THMBC transients, such as those associated with the generation of gas, the oxidation of the host rock during construction and operation, the generation of heat by spent-fuel and high level waste, as well as chemical perturbations induced by EBS materials may have several implications on the operational and long-term safety of a geological disposal facility. Under certain conditions, these transients, their spatial extent and their couplings have the potential to affect, either negatively or positively, safety functions fulfilled by one or several components of the disposal system (e.g. of typical safety functions: containment, flow limitation, ensuring stable mechanical conditions and retention). The importance of these transients in terms of intensity and spatial extent in time varies with the concept of the disposal facility, the site characteristics and the waste inventory.

Rationale for developing joint activities

Within a geological disposal facility, the occurrence of such THMBC transients is unavoidable. Hence, although the importance of a particular issue will vary with the concept of the disposal facility (design and materials of the EBS, e.g. the type of backfill and sealing materials used), the site characteristics) and the waste inventory, several issues related to THMBC transients are common to all disposal systems. Several findings are also expected to be transposable. Joint research could also greatly facilitate the availability of specific devices, facilities and tools suitable for carrying out experimental and modelling work in this area.

Research and/or horizontal activities of common interest

Chemical transients

The construction and the operation of a disposal facility will give rise to transients in the near-field that could affect the safety functions provided by various components (EBS and/or the host rock). For example, metallic and/or cementitious materials that will be used to condition and to immobilise the waste and to build the geological disposal facilities (gallery lining, groutings, sealing plugs, shaft lining…), coupled with other perturbations (such as the thermal transient), will induce chemical transients in the near-field. An improved understanding of such transients has already been developed in previous EU projects (e.g. former EU projects BENIPA [13], NF-PRO [10]). Nevertheless, there remains a need for further improvement and there is a common interest in pursuing R&D particularly on the spatial extent and evolution as well as the possible impact on safety functions of the following transients (see issues #1 and #2 in Table 4):

- Oxidative transient during the construction and operational phase, notably with regard to corrosion of metallic components;
- Chemical transient induced by metallic and/or cement components on clays. For example, the following specific issues are of common interest:
    - Chemical transients caused by cementitious materials at high temperature (e.g. pH fronts inducing mineral reaction zones in EBS and HR materials and at their interfaces, as well as their impact on radionuclide migration - this topic is partly addressed by the ongoing CEBAMA project [14]);
    - Chemical transients caused by the degradation of metallic materials (canister corrosion products/ions might replace ions in the bentonite and change its swelling properties) and the impact of microbial activity (impact on RN migration is covered in main topic 4, impact associated to gas generation/transport is covered hereunder).

Table 4: Main Topic 2 (Spatial extent and evolution of transient THMBC conditions in the near-field) issues and activities of common interest

SRA Main Topics and associated issues	Research activities (experiment and/or modelling works)	Horizontal activities		
		Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring…)
Main Topic 2: Transient THMBC conditions in the near-field				
#1. Oxidative transient	■			
#2. Chemical conditions induced by metallic and/or cement materials and components	■			
#3. Transients associated with gas production and migration		■		
#3.1 Generation processes and rates of safety-relevant gases other than H2	■			
#3.2 Influence of gas on geochemistry and microbial activity in HR and EBS	■			
#3.3 Gas migration through EDZ and EBS	■			
#4. Co-disposal of waste: interactions between different types of wastes		■		

Transients associated with gas generation and transport

Gas generation and transport in geological disposal facilities have been studied for more than 15 years in a series of successive international projects. These include the PEGASUS [15], EVEGAS [16], PROGRESS [17] and the GASNET [18] projects. While R&D on gas issues continued from the early 2000s within the national programmes, there was a hiatus of several years for comprehensive multinational projects [19]. In 2009, the FORGE project [20], under the auspices of the European Commission, was launched with participants from radioactive waste management organisations, regulators (TSOs included) and academia. The following issues were not addressed or fully resolved during past projects and need to be investigated in the future (see issues #3.1, 3.2 and 3.3 in Table 4):

- Generation processes and rates of safety-relevant gases other than H_2 (also investigated in the ongoing CAST project [21] as regards to the release of ^{14}C);
- Influence of gas on geochemistry and microbial activity in HR and EBS, and associated impact on radionuclide transport (microbial activity is also investigated in the ongoing MIND project [22]);
- Although considerable amount of work has been carried out on this topic, in particular in the past FORGE EC project [20], uncertainties still exist on processes driving gas migration through EDZ and EBS, associated in particular with possible saturation levels and scenarios of bentonite evolution or with other perturbations such as alkaline plume. Therefore, there is still a need to improve the process understanding.

Moreover, a common interest exists for exchanges on the interpretation of the outcomes of the former FORGE project [20] (see issue #3 in Table 4).

Transients associated with co-disposal of radioactive waste

The possible interactions between different kinds of waste that would be disposed of in the same facility are of common interest for performing horizontal activities (exchanging on practices and developing common positions, see issue #4 in Table 4), for example how to take into account in the concept of a disposal facility for possible interactions between the different kind of waste.

6.3 MAIN TOPIC 3: EVOLUTION OF EBS MATERIAL PROPERTIES

Importance of the main topic to safety

The safety of a geological repository is to a great extent determined through the effectiveness of a multi barrier system which is the safety basis for most of the countries dealing with radioactive waste disposal. This system consists of natural barriers such as the overlaying rock and host rock as well as engineered barriers. The engineered barriers like waste canisters, buffer materials, backfill and seals are components of the engineered barrier system (EBS). The EBS as part of the MBS plays an essential role in terms of long term safety of the DGR. In most safety concepts the primary safety functions of an EBS are the containment of radionuclides and long-term minimisation/retardation of radionuclide releases. As a consequence of the THMBC transients the EBS material properties will evolve. This will in turn affect safety functions of the disposal facility.

Rationale for developing joint activities

Within a geological disposal facility, the occurrence of THMBC transients is unavoidable. Although the importance of a particular issue will vary with the concept of the disposal facility, the site characteristics and the waste inventory, several issues related to EBS material evolution are common to all disposal systems. For example, several common materials for EBS are used (bentonite, metallic components, concrete). Further some of the relevant safety aspects are of common importance (e.g. canister/ cask lifetime, homogeneity of the buffer material). Several findings are expected to be transposable. Joint research will also greatly facilitate the availability of specific devices, facilities and tools suitable for carrying out experimental and modelling work in this area.

Research and/or horizontal activities of common interest

The EBS covers a wide range of different components. Each component is a man-made barrier which consists of engineered materials. It is essential to know how these materials behave in different situations which might occur in the development of the site and disposal system. There is a common level of interest for pursuing R&D in the following fields of research (see issues #1 to 3 in Table 5).

- Heterogeneous behaviour of bentonite components.
    - Conceptual improvement of existing models is needed to efficiently account for the time-dependence of HM processes.
    - The coupling of these HM processes with T and C processes should also be improved. For instance, the bentonite transformation due to interactions with canister material is of interest at long term. In particular, the consequences on mechanical stability, swelling pressure and related radionuclide migration (covered by issue #1 of MT4) are not well known for the disturbed bentonite.
    - The influence of these processes on the effective closure of a disposal facility (e.g. performance of seals and plugs on the long term and large scale) should be further investigated.
- Evolution of metallic components. For example, study of metal (e.g. steel, copper) corrosion in repository conditions or of canister design lifetime.
- Evolution of cementitious components. Note that several aspects of cement material evolution are covered by the EC H2020 CEBAMA project [14]. As an example, the impact of radiations on cement material properties important for safety could be investigated.

There is also a common interest for exchanging on container design and manufacturing issues (e.g. modelling codes and standards and QA/QC programs and procedures for container design and manufacturing). If not properly managed these issues could affect the long term behaviour of metallic components. They could be discussed within issue #2.

Table 5: Main Topic 3 (Evolution of EBS material properties) issues and activities of common interest

SRA Main Topics and associated issues		Research activities (experiment and/or modelling works)	Horizontal activities		
			Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring...)
Main Topic 3: Evolution of EBS material properties					
#1.	Heterogeneous behaviour of bentonite components	■			
#2.	Behaviour of metallic components	■	■		
#3.	Behaviour of cementitious components	■			

6.4 MAIN TOPIC 4: RADIONUCLIDE BEHAVIOUR IN DISTURBED EBS AND HR

Importance of the main topic to safety

The radionuclide transport properties of disturbed EBS and host rock could change significantly compared to undisturbed conditions. Several possible perturbations could originate from the THMBC transients (see main topic 2). Such perturbations will affect the radionuclide retention safety function of EBS and HR and thus the long term safety of a disposal facility.

Rationale for developing joint activities

Although the importance of a particular perturbation will vary according to the disposal facility concept, the site characteristics and the waste inventory, several issues related to radionuclide migration in disturbed EBS and host rock are common to all disposal systems. However, it should be noted that the perturbations are highly dependent on the type of host rock (e.g. clay, granite or salt) and the design and materials of the EBS (e.g. the type of backfill and sealing materials used). Joint research will also greatly facilitate the availability of specific devices, facilities and tools suitable for carrying out experimental and modelling work in this area.

Table 6: Main Topic 4 (Radionuclide behaviour in disturbed EBS and HR) issues and activities of common interest

SRA Main Topics and associated issues		Research activities (experiment and/or modelling works)	Horizontal activities		
			Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring...)
Main Topic 4: Radionuclide behaviour in disturbed EBS and HR					
#1.	Competition between sorption of radionuclides and other elements from EBS/waste	■			
#2.	Influence of organic matter on radionuclide migration	■			
#3.	Influence of the thermal transient on RN migration in EBS and HR	■			
#4.	Influence of microbial activity on RN migration	■			
#5.	Transport of volatile radionuclides in the disposal system	■			

Research and/or horizontal activities of common interest

Current performance assessment studies generally include predictions for radionuclide migration using a constant, radionuclide dependent Kd approach, taking into account uncertainty in “all other geochemical processes” by a bandwidth for individual Kd’s. The conservatism of such an approach with regards to the impact on radionuclide transport of possible perturbations needs to be investigated. For instance, the following perturbation needs to be considered (see issues #1, 2, 3 and 4 in Table 6):

- Degradation product fronts, which could notably include corrosion products, as well as metal fronts (Mn, Cu, Ni, Fe, …) that change RN sorption and sorption competition and bentonite properties in general;
- Organic matter fronts affecting RN sorption in cementitious environment and their interaction with Fe;
- Temperature fronts influencing mineral precipitation/dissolution rates;
- Microbial activity related to these fronts.

RN migration in colloids could also be investigated in this main topic.

Although working groups (e.g. NEA thermochemical database project) and former EC projects focused on some of these aspects (e.g. EC FP7 SKIN [23] and EC FP7 RECOSY [24] projects), there is still a common interest in starting new R&D activities for these issues.

Approaches to explaining and assessing sorption phenomena more sophisticated than the Kd approach are already proposed in the literature (e.g. electrostatic DL, TL or non-electrostatic surface complexation ion-exchange models using sites (multi-site) and sites capacities models). Such approaches could be used and developed further for investigating radionuclide migration in disturbed EBS and host-rock. Furthermore, the transferability of experiment results to in situ conditions is also an important issue that has to be considered when investigating topics related to radionuclide migration.

In the framework of this main topic, the transport of volatile radionuclides in the disposal system needs to be investigated too (see issue #5 in Table 6). Concerning C-14, note that its behaviour and impact strongly depend on its speciation, which is currently investigated in the CAST project [21].

6.5 MAIN TOPIC 5: SAFETY-RELEVANT OPERATIONAL ASPECTS

Importance of the main topic to safety

According to international safety standards (IAEA Specific Safety Guide No SSG-14 related to Geological Disposal Facilities for Radioactive Waste [25]), the safety case for a geological disposal facility includes safety assessments for the operational period and for the post-closure period, at the early stage of the initial site investigation and preliminary facility design. The safety case and supporting safety assessments should become more detailed and comprehensive as development and operation of the geological disposal facility proceeds. While international programs related to the post-closure safety of geological disposal facilities have been carried out for decades, the safety during operation of these facilities came more recently into discussion in international projects (e.g. the IAEA projects GEOSAF [26], the European projects MODERN [27]) as the so-called "more advanced programs" enter their pre-licensing step. Actually, the very specific features of geological disposal facilities currently developed in Europe (underground vaults, tight areas, operation time- and space-scales, co-activity…) question the direct transposition of knowledge developed for the safe operation of already existing (aboveground) nuclear facilities. Furthermore, the state of the facility at its closing stage may depend on the operational phase as events occurring during the operation may impact provisions expected to fulfill post-closure safety functions.

Rationale for developing joint activities

Though parts of a safety case for the operational period are expected to be very design-specific, SITEX-II partners identified common interest in sharing and/or developing tools and approaches (including scenarios) to support the expertise function assessment of safety cases regarding major operational issues for all countries developing and licensing disposal facilities, such as monitoring or fire hazards, as summarized below. Experience has been gained with pre-licensing processes in a number of member countries, which provides for meaningful discussion and valuable insights for countries with less advanced programs. However, there are still issues that require further investigations.

Table 7: Main Topic 5 (Safety relevant operational aspects) issues and activities of common interest

SRA Main Topics and associated issues	Research activities (experiment and/or modelling works)	Horizontal activities: Exchange on practices, develop common positions	Horizontal activities: Develop states of the art	Horizontal activities: Transfer knowledge (eg. training, tutoring…)
Main Topic 5: Safety relevant operational aspects				
#1. Efficiency of the monitoring system over the operational period	■	■		
#2. Assessment of the risk of fire and explosion	■	■		■
#3. Assessment of the risk of flooding		■		
#4. Influence on long term safety of pre-closure disturbances		■		

Research and/or horizontal activities of common interest

Preventing a massive release of activity due to a fire or an explosion is a major safety issue during the operational phase of a geological disposal facility (see the topics in Table 7). The review of fire and explosion hazards assessment in such an environment should account for requirements in both the underground (mining) and nuclear fields. It requires reviewing merged standards and further developing independent modelling tools to simulate the behaviour of a fire and the generated smokes in galleries and disposal vaults, using theoretical laws and parameters values potentially different from those accounted for in the safety case. There is also a need regarding the ventilation of galleries while there may be explosion hazards when hydrogen is released by waste packages. In particular, the main parameters of air fluxes are difficult to anticipate due to the complex network of underground tunnels currently developed in national programs and in some cases, to the piling of waste packages in disposal vaults. Some modelling actions (in situ test being of WMO responsibility) may be needed in the future, especially in view of counter-calculations when reviewing safety cases. Furthermore, the behaviour of the packages from some waste streams (such as bitumen waste) in the case of a fire or of run-away (uncontrolled) chemical reactions, as well as that of its concrete overpacks, concrete liner and even the host-rock (locally), needs to be further studied so as to provide possible levels of containment failure; it thus challenges the provisions made by the implementer to prevent such accidents and to limit their consequences.

Whatever the provisions made, the occurrence of appropriate scenarios of accidents, including but not limited to major ones such as fire/explosion or flooding, should be accounted for in the safety case – and thus be reviewed - as well as the remediation of the facility, which is an issue to the extent that it may impact the post-accident safety. Besides, events or accidents occurring during the operational phase may impact components with a post-closure safety function or their environment, leading to e.g. a decrease in their performances (see above). Damage to overpacks due to handling, local flooding or heating of host-rock can be mentioned for illustration purpose. On a more general level, the disposal facility shall be operated in such a manner to preserve the safety functions assumed in the safety case that are important to safety after closure (IAEA Specific Safety Guide No SSG-14 [25]). Exchanges in these fields to get hold of outcomes from other international project (e.g. GEOSAF [26] as mentioned above) and further develop common positions would be helpful in terms of challenging the assessment made by the implementer and homogenization of expertise approaches.

At last, monitoring is, in addition to the provisions made to prevent accidents, one of the paramount safety provisions to implement. As stated by the above mentioned IAEA Guide, monitoring provides input to safety assessments, continuing assurance of operational safety of the facility and confirmation that actual conditions are consistent with the assumptions made for safety after closure. The ageing of safety structures and components (SSC) is of particular concern for geological disposal facilities as operations over periods of around one hundred years are foreseen. At present, strategies and tools for such monitoring are still a vast research topic, as shown by the European project Modern2020 [28] launched in 2015. The expertise function must be involved in this research field (beyond Modern2020) to develop its own expertise capability; exchanges in this area would also be needed to share the state of the art and practice in this field.

6.6 MAIN TOPIC 6: MANAGING UNCERTAINTIES AND THE SAFETY ASSESSMENT

Importance of the main topic to safety
As stated by the NEA-MESA project [29]:

> *"a safety assessment is a systematic analysis of the hazards associated with a geological disposal facility, and the ability of the site and design to provide the safety functions and meet technical requirements. Safety assessment is an essential component of the safety case. From a regulatory perspective, providing the evidence to support the claims made in the safety assessment is just as important as the safety assessment calculations themselves."*

The development and use of appropriate assessment methodologies are thus essential for building confidence in the results of the safety assessment. Furthermore, as uncertainties are always associated with assessment results, the substantiation that they have been properly identified, characterised, incorporated in the analyses and associated in decision making, and managed is central to the demonstrating the SC and developing confidence in the SC.

Rationale for developing joint activities
The development of safety assessment methodologies and the management of uncertainties are issues which apply to all countries developing and licensing disposal facilities. Experience has been gained in a number of member countries and in the framework of international projects (e.g. [29], [30]), which provides for meaningful discussion and countries with less advanced programmes would gain valuable insights.

Research and/or horizontal activities of common interest
There is a common interest in exchanging and developing states of the art on the management of uncertainties associated with site characteristics (see issues #1 and 2 in Table 8):

- The present state of the site (e.g. uncertainties associated with the upscaling of lab measurements to site characteristics, the transposition of characteristics from one site/host rock to another, transfer of (sorption) data from diluted systems to compacted systems, ...);
- Possible geodynamics and tectonic perturbations of the site at the long term.

Furthermore, there is a common interest in transferring knowledge and exchanging about review approaches for the following issues (see #3 and 4 in Table 8):

- General methodologies for the safety assessment identifying the different components and activities of a safety assessment (data clearance, comprehensiveness checking, synthesis of evidence, arguments and analyses, …), the interactions between these activities and with other types of activities (design, monitoring, …) as well as a general methodology for managing uncertainties;

- Safety assessment models: e.g. of specific issues are the limitations, difficulties and uncertainties associated with safety assessment models (including the justification that models are fit for their purpose).

Table 8: Main Topic 6 (Managing uncertainties and the safety assessment) issues and activities of common interest

SRA Main Topics and associated issues		Research activities (experiment and/or modelling works)	Horizontal activities: Exchange on practices, develop common positions	Horizontal activities: Develop states of the art	Horizontal activities: Transfer knowledge (eg. training, tutoring…)
Main Topic 6: Managing uncertainties and the safety assessment					
#1.	Uncertainties associated with site characteristics		■	■	
#2.	Management of uncertainties associated with geodynamics and tectonic movements		■	■	
#3.	General methodologies for the safety assessment		■		■
#4.	Safety assessment models		■		■

6.7 MAIN TOPIC 7: LIFECYCLE OF A DISPOSAL PROGRAMME AND ITS SAFETY CASE

Importance of the main topic to safety

The lifecycle of a disposal facility consists of several phases (see §4.2). All along these phases, work important to safety will be achieved, 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 [25] this work should be carried out within the framework of a safety case which collects scientific, technical, administrative and managerial arguments and evidences in support of the safety of a disposal facility.

The safety of radioactive waste management encompasses the activity of human beings in order to protect human health and the environment but entails a longer-term objective of reaching a permanent state of safety where a human activity is no more necessary to maintain safety. In this perspective, radioactive waste management entails both inter and intra generational dimensions that makes this activity a complex issue for humanity. In addition, geological disposal entails very sensitive considerations on the justification of dedicating forever, to radioactive waste management, a geological location that is part of the earth that present generations have in common with future human beings. Decision-makers should therefore be aware of social dimension of radioactive waste management and more specifically of the implementation of long-term geological disposal. Specific issues, for which there is a common interest to address both the technical and the societal aspects, in collaboration with representatives from the CS, will thus also be considered in this main topic.

Rationale for developing joint activities

This main topic applies to all countries developing and licensing disposal facilities. Experience has been gained with (pre)licensing processes in a number of countries, which provides for meaningful discussion and countries with less advanced programmes would gain valuable insights.

Research and/or horizontal activities of common interest

Evaluation of experience with different country arrangements would enable the identification of possible gaps or weaknesses in the understanding of expertise function expectations associated with the lifecycle of a disposal programme. This would provide an opportunity to overcome any such gaps or weaknesses and would assist in strengthening a harmonized approach. A common view on areas of significant safety impact could be identified and proposals formulated for an appropriate degree of regulatory control.

Table 9: Main Topic 7 (Lifecycle of a disposal facility and the safety case) issues and activities of common interest

SRA Main Topics and associated issues		Research activities (experiment and/or modelling works)	Horizontal activities		
			Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring...)
Main Topic 7: Lifecycle of a disposal programme and its safety case					
#1.	Methods to review the safety case		[redacted]		[redacted]
#2.	Assessment of the technical feasibility of a geological disposal concept		[redacted]		
#3.	Evolution of the safety case content with the lifecycle of the disposal programme		[redacted]		[redacted]
#4.	Organization of the pre-licensing phase		[redacted]		[redacted]
#5.	Reversibility and Retrievability		[redacted]		
	Example of topics for which technical and societal aspects could be investigated:				
#6.	Application of the optimization principle	[redacted]	[redacted]		
#7.	License of disposal operation	[redacted]	[redacted]		
#8.	Conditions for closure	[redacted]	[redacted]		
#9.	Site selection process	[redacted]	[redacted]		
#10.	Safety culture in the context of geological disposal	[redacted]	[redacted]		
#11.	Intergenerational governance of the operational phase	[redacted]	[redacted]		

The following issues are of common interest for horizontal activities (see Table 9 for details about the kind of activities):

- Develop guidance for reviewing the safety case (this issue is currently covered by the SITEX-II WP2 “Developing a joint review framework”);
- Assessment of the feasibility of a geological disposal concept (e.g. expectations of the expertise function on the methodology that should be followed to assess the feasibility);

- Evolution of the safety case content with the lifecycle of the disposal facility;
- Organization of the pre-licensing phase (e.g. assurance of the quality of the work undertaken prior to the formal licensing processes, its appropriateness and its compliance with safety requirements, credibility of the regulatory process with stakeholders at this stage of a project development);
- Reversibility and retrievability (e.g. implication of these principles in term of design and performance of the facility).

As explained at the beginning of section 6 and in section 8.1, in the future, for each new project or activity based on the SRA, the expertise function will check with CS representatives which of the Social and Citizen Sciences aspects presented in section 8.1 could be relevant and how to integrate them to the technical aspects that have to be investigated. Examples of topics that could give rise to such “complex” (multidisciplinary) projects or activities are given below.

- Application of the optimization of the radiation protection principle (See [31], [32]) (e.g. how to consider the concerns of the CS in the application of the optimization process);
- License of disposal operation (e.g. develop a structured socio-technical understanding of the possible successive decision-making steps to confirm the design and operation modes of a geological disposal facility in view of a full commissioning license);
- Conditions for closure (e.g. examining the technical and socio-political criteria on which a partial or full closure could be decided);
- Site selection process (e.g. develop a common understanding of the socio-technical expectations about the organization of the process and the criteria for site selection);
- Safety culture in the context of geological disposal: the objective is to investigate the conditions and means for developing interactions between various categories of stakeholders and the public into the context of reviewing the safety of RWM strategies and geological disposal.
- Intergenerational governance of the operational phase (e.g. managing of changes in the socio-political framework, elaborating sustainable societal memory patterns, during the operational and the post-closure phase, …).

7 Synergistic topics of SITEX with other platforms

According to SITEX-II WP1, research activities (experiment and/or modelling works) identified in this SRA could be implemented in the framework of a joint programme, to the following conditions for preserving the independence of organizations fulfilling an expertise function:

- When shared experiments are developed in a joint project, all participants have a say on their design;
- There should be a transparency of the codes/data/results obtained: all parties have access to acquired data, codes, information… (i.e. for codes, this means that benchmark could at least be possible).
- Organizations fulfilling an expertise function should perform an independent analysis of the results from the one of WMOs. It is of crucial importance that implementing and expertise functions can use separately the results obtained with respect to their own function within their national programme. However, this condition depends on the nature of the results and does not apply when the scope of the analysis is limited to a phenomenological understanding of specific processes.

Concerning horizontal activities, WP1 partners have no objection against implementing such activities within the framework of a joint programme, if the following conditions are met:

- The objective of the activities "exchanging on practices" is fostering a mutual understanding on important issues and principles and not necessarily reaching common positions.
- Impartiality has to be ensured in the process of establishing states of the art and training activities.

8 Stakeholder engagement

In the framework of the development of this SRA, SITEX-II WP1 ("Programming R&D") organizations fulfilling an expertise function have engaged interactions with SITEX-II WP4 Task 1 ("CS interacting with R&D"). The following work has been achieved by WP4:

- Review of former SITEX deliverable D3.1 (R&D orientations for TSO) [7];
- Review of the possible SRA topics built in step 1 of the SRA methodology (see §5.1);
- Review of the draft SRA established 6 months after the start of the project (T0 +6, milestone M1.1).

The conclusions of these review activities were presented and discussed by WP4 with representatives of the CS during the first WP5 ("Integration and dissemination of project results") SITEX-II workshop and during one WP4 meeting. These conclusions, which will be documented in the SITEX-II deliverable D4.1, are summarized hereafter.

8.1 CONSIDERATION OF SOCIAL AND CITIZEN SCIENCES IN FUTURE RESEARCH PROJECTS AND ACTIVITIES

Past and current work on radioactive waste management strategies (including the geological disposal of radioactive waste) are mainly focused on scientific and technical issues. Nowadays, the complexity of some radioactive waste management issues rises and more specifically the societal dimensions (social, political, ethical, ontological) of the decision-making processes. In several programmes, the CS finds itself largely outside the process of drafting and of implementing the radioactive waste management strategies, while implementers and public authorities struggled to involve society at the latest stages of technical decision-making when almost all options are predetermined, yielding to a limited embedding of social and technical issues. Actually, addressing the complexity of radioactive waste management issues entails involving both:

- "**Social science**" to address properly social/societal dimensions that are attached to the whole long-term picture of radioactive waste management and more specifically to geological disposal, and,
- **"Citizen science"** meaning here involving directly people (amateur or non-professional scientists) in the production of trustworthy and reliable scientific knowledge that is required for RWM.

The integration of Social and Citizen Science aspects should be considered in any new research projects or horizontal activities that will be launched in the future based on this SRA. Such possible Social and Citizen Science aspects were identified by WP4 and are synthetized hereunder.

- Sharing R&D knowledges: the purpose of this research is to develop an interaction framework of institutional researchers with Civil Society Organisations (at local, national and EU levels) and Civil Society Experts for exchanging, interpreting and evaluating information along technical research activities, notably on Deep Geological Repository (goals, methodology, preliminary results, final results).
- Uncertainty, epistemology and social trust along RWM and geological disposal implementation: this research topic will 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 other stakeholders in the context of different kinds of hazardous activities (including nuclear and other risks).
- Aggregating a diversity of people, unfold capacities of collective intelligence along RWM and geological disposal implementation: the purpose of this research is 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.

- Socio-technical hybridization of geological disposal implementation strategies: the aim is to examine the conditions and means for enabling the fabric of mixed problematic that hybridize technical and social perspectives and the matching of values in the early framing of the problems.
- Safety culture in the context of geological disposal: the objective is to investigate the conditions and means for developing interactions between various categories of mandated actors and the public into the context of reviewing the safety of RWM strategies and geological disposal.
- Ontological and axiological commitments of geological disposal stakeholders: the research aims at identifying the main paradigms or reference frames of the radioactive waste management stakeholders and societal actors. Then, the potential need, scope, use and role for “ontological diplomacy” processes for the actors to come up with an agreement could be identified.
- Background democratic culture of geological disposal implementation: this research aims at identifying the political conditions for RWM to be addressed by the public and the other various concerned actors.

All WP1 partners fulfilling an expertise function recognize the importance of considering these social and citizen science aspects in future research projects or activities developed based on this SRA. Depending on their mandate, as well as their expertise and resources, some organizations fulfilling an expertise function could directly participate in these social and citizen sciences aspects.

8.2 OTHER ASPECTS CONSIDERED IN THE DEVELOPMENT OF THE SRA

In addition to what is presented in section 8.1, the following input of WP4.1 has been considered in the SRA.

- WP4.1 stressed that the SRA should include, beside R&D on geological disposal, R&D on possible alternative management options. WP1 agrees that the SITEX network could consider R&D issues related to management options other than geological disposal, if relevant to several national programmes. However, this first version of the SRA is specifically focused on disposal in underground facilities.
- WP4.1 stressed that the challenging issues should be identified as such in the present SRA. This has been done in section 7, though not exhaustively.
- WP4.1 stressed that exchanges on fundamental principles for evaluating the safety cases should be strengthened in the SRA. This point was also raised by SITEX-II WP2 (“Developing a joint review framework”). Within the framework of the first step of the SRA development methodology, a cross check was made between the possible SRA topics and the Safety topics identified within the former SITEX project. Several topics on important safety principles were added and those for which there is a common interest are notably gathered in main topics 6 and 7 of the SRA.

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10 Appendices

APPENDIX 1: LIST OF POSSIBLE R&D TOPICS CONSIDERED FOR DEVELOPING THE SRA (STEP 1 OF THE METHODOLOGY) AND QUESTIONNAIRE SENT TO WP1 PARTNERS FOR APPRAISING THE COMMON LEVEL OF INTEREST.

WP1 PARTNER: [to be completed] **PLEASE READ THE PROVIDED GUIDELINES BEFORE FILLING THE TABLE**

Key issues	Key topics	R&D topics			Questionnaire								
		#	Corresponding SITEX WP2 Safety Topics	Brief description	Q1: Is this topic relevant for the disposal concept(s) considered in your country?	Q2: Do you think that your need for expertise and skills could be fulfilled by:				Q3: What is your level of interest in participating in joint activities?	Justification of the level of interest	Q4: What is your level of urgency for developing expertise and skills in this topic?	Justification of the level of urgency.
						Q2.1: performing a state of the art?	Q2.2: a transfer of knowledge?	Q2.3: estabilishing an international working group?	Q2.4: performing R&D?				
Key Issue 1: data acquisition	Source term	1	23b waste characterisation and 26 uncertainties 20 waste acceptance	Uncertainties associated with the characterization of the waste inventory (radiological and non-radiological characteristics).									
	EBS	2.1	26 uncertainties 15 design 5 passive means, 6 good engineering, 7 isolation and containment 12d design stratgy	Uncertainties associated with the determination of bentonite based EBS									
		2.2	26 uncertainties 15 design 5 passive means, 6 good engineering, 7 isolation and containment 12d design stratgy	Uncertainties associated with the determination of cement based EBS									
		2.3	26 uncertainties 15 design 5 passive means, 6 good engineering, 7 isolation and containment 12d design stratgy	Uncertainties associated with the determination of metallic based EBS									
	HR	3.1	26 uncertainties 14 site selection	Uncertainties associated with the determination of HR geological properties									
		3.2	26 uncertainties 14 site selection	Uncertainties associated with the determination of HR chemical and geochemical properties									
		3.3	26 uncertainties 14 site selection	Uncertainties associated with the determination of HR transport properties									
		3.4	26 uncertainties 14 siteselection	Uncertainties associated with the determination of HR thermal properties									
		3.5	26 uncertainties 14 site selection	Uncertainties associated with the determination of HR mechanical properties									
		4	26 uncertainties 14 site selection	Uncertainties and limitations associated with the transfer of data acquired for one site to another (same HR) or for one HR to another									
	Surrounding geosphere and biosphere	5	26 uncertainties 14 site	Uncertainties associated with the determination of site hydrogeological properties									
		6	3 protection of the environment 26 uncertainties 14 siteselection	Uncertainties associated with the determination of biosphere properties									
		7	26 uncertainties 14 site selection	Uncertainties associated with the determination of the geological properties									
Key Issue 2: Processes on which safety rely	Waste form performance	8.1	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: spent fuel, including the instant release fraction									
		8.2	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: graphite bearing waste									
		8.3	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: vitrified waste									
		8.4	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: bituminized waste									
		8.5	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: cemented waste									
		8.6	23 b Characterisation, knowledge and system understanding - waste	Understanding of the processes upon which safety functions fulfilled by waste forms rely: metallic waste									
	EBS performance	9.1	23c Characterisation, knowledge and system understanding - engineered components	Understanding of the processes upon which safety functions fulfilled by EBS rely: bentonite based EBS									
		9.2	23c Characterisation, knowledge and system understanding - engineered components	Understanding of the processes upon which safety functions fulfilled by EBS rely: cement based EBS									
		9.3	23c Characterisation, knowledge and system understanding - engineered components	Understanding of the processes upon which safety functions fulfilled by EBS rely: metallic based EBS									
	HR performance	10.1	23 d Characterisation, knowledge and system understanding - site	Understanding of the processes upon which safety functions fulfilled by HR rely: clayey HR									
		10.2	23 d Characterisation, knowledge and system understanding - site	Understanding of the processes upon which safety functions fulfilled by HR rely: granitic HR									
		10.3	23 d Caracetrisation, knowledge and system understanding - site	Understanding of the processes upon which safety functions fulfilled by HR rely: HR salt									
	Radionuclide transfer in the surrounding environment	11	1 c RP dose limits	Understanding of the processes governing radionuclide transfer in the geosphere									
		12	1 c RP dose limits	Understanding of the processes governing radionuclide transfer in the biosphere									

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Key Issue 3: processes affecting the system evolution	Perturbations induced by construction and operation	13.1	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback nd monitoring	Understanding of the HM perturbations of the HR induced by excavation and operation (including possible subsequent healing of the rock) and assessment of their potential impacts on the performances of the HR and EBS: clayey HR									
		13.2	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback nd monitoring	Understanding of the HM perturbations of the HR induced by excavation and operation (including possible subsequent healing of the rock) and assessment of their potential impacts on the performances of the HR and EBS: granitic HR									
		13.3	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback nd monitoring	Understanding of the HM perturbations of the HR induced by excavation and operation (including possible subsequent healing of the rock) and assessment of their potential impacts on the performances of the HR and EBS: salt HR									
		14	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback nd monitoring	Understanding of the perturbations induced by the oxidation of clay during excavation and operation and assessment of their potential impact on the performances of the repository components									
		15	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback nd monitoring	Understanding of the perturbations induced by microbial activity development in repository conditions and assessment of their potential impact on the performances of the repository components									
		16	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback and monitoring	Understanding of the perturbations induced by accidents or incidents during operational phase and assessment of their potential impact on the performances of the repository components in the long term									
	Waste-induced perturbations	17.1	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback and monitoring	Understanding of the THMBC perturbations induced by temperature increase after waste emplacement and assessment of their potential impact on the performances of the HR									
		17.2	12 c Design and implementation strategy 16 construction 23 Characterisation, knowledge and system understanding c engineered, d site e operating feedback and monitoring	Understanding of the THMBC perturbations induced by temperature increase after waste emplacement and assessment of their potential impact on the performances of the EBS									
		18.1	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the processes that may lead to gas generation in repository conditions									
		18.2	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the perturbations induced by gas generation and their potential impact on the performances of the HR									
		18.3	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, e operating feedback and monitoring	Understanding of the perturbations induced by gas generation and their potential impact on the performances of EBS									
		19.1	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the perturbations induced by radiolysis and assessment of their potential impact on the performances of the HR									
		19.2	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, e operating feedback and monitoring	Understanding of the perturbations induced by radiolysis and assessment of their potential impact on the performances of the EBS									

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		20.1	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the THMBC perturbations induced by bitumen in clayey rock or materials (swelling, nitrate plume, nitrogen production,...) and assessment of their potential impact on the performances of the HR									
		20.2	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, e operating feedback and monitoring	Understanding of the THMBC perturbations induced by bitumen in clayey rock or materials (swelling, nitrate plume, nitrogen production,...) and assessment of their potential impact on the performances of the–EBS									
		21	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the processes that could cause the formation of a critical mass in repository conditions									
	EBS-induced perturbations	22	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the HMC perturbations induced by cementitious materials in clayey materials (in HR, EBS or waste forms) and assessment of their potential impact on the performances of repository components									
		23	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the HMC perturbations induced by metallic materials on clay materials (in HR, EBS or waste forms - excluding gas formation, covered by Topics 18.2 and Topic 18.3) and assessment of their potential impact on the performances of the repository components									
	HR induced perturbations	24	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the HMC perturbations induced by clayey HR in cementitious materials and assessment of their potential impact on the performances of EBS									
		25	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	Understanding of the HMC perturbations induced by clayey HR in metallic materials and assessment of their potential impact on the performances of EBS									
		26	12 c Design and implementation strategy 23 Characterisation, knowledge and system understanding b waste c engineered, d site e operating feedback and monitoring	§									
	Natural external perturbations	27	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledeg and system understanding	Understanding of the perturbations induced by geodynamics (including glaciation, erosion, changes in hydraulic gradients,...) and assessment of their potential impact on the performances of repository components									
		28	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledeg and system understanding	Understanding of the perturbations induced by marine transgression or regression (erosion, change of salinity, changes in hydraulic gradients,...) and assessment of their potential impact on the performances of repository components									
		29	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledeg and system understanding	Understanding of the perturbations induced by tectonic movements (including subsidence/uplift) and assessment of their potential impact on the performances of repository components									
		30	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledeg and system understanding	Understanding of the perturbations induced by earthquakes and assessment of their potential impact on the performances of repository components									
		31	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledge and system understanding	Understanding of the perturbations induced by climate change (other than Topic 27 and Topic 28) and assessment of their potential impact on the performance of repository components									
	Human-induced perturbations	32	4 DiD and robustness, 14 site selection, 23 Characterisation, knowledeg and system understanding	Understanding of the perturbations induced by human activities and inadvertent intrusion and assessment of their potential impact on the performances of repository components (e.g. Groundwater pumping, mining, ...)									
		33	6 Good engineering, proven techniques qnd feasibility 12c Design and implementation strategy 16 Construction	Feasibility of construction of waste packages									

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Key Issue 4: technical feasibility		34.1	6 Good engineering, proven techniques qnd feasibility 12c Design and implementation strategy 16 Construction	Feasibility of constructing/closing a repository meeting the operational and post-closure safety requirements (excavation of galleries, disposal cells,...)									
		34.2	6 Good engineering, proven techniques qnd feasibility 12c Design and implementation strategy 16 Construction	Feasibility of constructing/closing a repository meeting the operational and post-closure safety requirements: backfilling of galleries									
		34.3	6 Good engineering, proven techniques qnd feasibility 12c Design and implementation strategy 16 Construction	Feasibility of constructing/closing a repository meeting the operational and post-closure safety requirements: construction of seals									
		34.4	6 Good engineering, proven techniques qnd feasibility 12c Design and implementation strategy 8 reversibility and retrievability	Feasibility of constructing/closing a repository meeting the operational and post-closure safety requirements: retrievability and reversibility									
		35	6 Good engineering, proven techniques and feasibility 17 a, i emplacement	Feasibility of operating a repository meeting operational safety requirements (e.g. Feasibility of waste emplacement)									
		36	6 Good engineering, proven techniques and feasibility, 17 f inspecion 21 Monitoring	Feasibility of implementing a monitoring system without jeopardizing the performances of the repository components									
Key Issue 5: operational safety assessment (ST 1 RP)		37	1c Rp limits	Ventilation of the repository galleries and shafts									
		38.1	17a general aspects of operation, b operational feedback, e emergency preparedness	Methodology to identify/assess hazards possibly occurring in an underground nuclear facility: Fire and explosion hazards									
		38.2	17i receiving handling, emplacement	Methodology to identify/assess hazards possibly occurring in an underground nuclear facility: waste package handling hazards									
		38.3	11 concurrent activites	Methodology to identify/assess hazards possibly occurring in an underground nuclear facility: hazards due to activities performed in parallel (co-activity) e.g. construction of new galleries in parallel of waste emplacement									
		38.4	17 e emergency preparedness f monitoring	Methodology to identify/assess hazards possibly occurring in an underground nuclear facility: criticality risk									
		39	17 f maintenance, monitoring	Ageing management of SSC									
		40	17e Emergency preparednaess	Emergency planning									
		41	25 assessment of possible radiation risks 26 uncertainties 28 conservative / realistic 29 scenarios, 30 models 32 operationalk safety assessment	Modelling difficulties, limitations and uncertainties associated with operational safety assessment models									
Key Issue 6: post closure safety assessment	Assessment methodologies	42	12 a safety assessment strategy 33 Long term sfaety asessment	General methodologies to perform safety assessment.									
		43	12 a safety assessment strategy 33 Long term safety assessment	Approaches to ensuring that all relevant FEPs and uncertainties are adequately taken into account in the safety assessment.									
		44	12 a safety assessment strategy 33 Long term safety assessment	Approaches for developing an appropriate set of scenarios.									
		45	33 Long term safety assessment	Approaches to substantiate that a model is "fit-for-purpose" (transition from scenario to model).									
		46	12 a safety assessment strategy 33 Long term safety assessment	Methods and tools to characterize, analyse and treat uncertainties?									
		47	12 a safety assessment strategy 33 Long term safety assessment	Approaches to assessing the technical feasibility of a disposal concept or design.									
	Model development	48	33 Long term safety assessment 24 Timescales and timeframes 25 Assessment of radiation risk 26 uncertainty 27 deterministic vs probabilistic conservatism vs realism	Modelling approaches (e.g. deterministic vs. probabilistic), difficulties, limitations and uncertainties associated with long term safety assessment models									
		49	1. Optimization of radiation protection	Interpretation of the principle and its implementation at different programme stages (factors, existing circumstances, weighting criteria,...)									
		50	3. Protection of the environment	Approaches for assessing protection of non-human biota									
		51	4. Defence-in-depth & robustness	Practical implementation of the DiD principle for geological disposal (complementarity, independence, role of controls,...) (as mainly NPP focused)									
		52	9. Graded approach	Interpretation of the principle and its implementation at different programme stages									
		53	10. Step by step development	Pre-licensing process (having the regulator involved early before a licence application submitted, including dealing with requests of the public)									

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		54	Management (12b. Management strategy &	Elements and content of the management strategy. Assessment of compliance with requirements associated with available resources (i.e. organisational structure, staffing, skills, experience and knowledge, training/recruitment programs, subcontractors, financial resources,...), preservation of records and knowledge, responsibilities (e.g. interfaces between the responsibility of the licensee and the organisations responsible for the waste before sending to the repository), management of construction activities (QA/QC, information that shall be gathered during construction), management of design modifications,...									
		55	Design (12c. Design & implementation strategy & 15. Design)	Elements and content of the design and implementation strategy, development process of the "design basis", of the design requirements & specifications,...									
		56	14. Site selection	Site selection method, attributes and criteria, weighting of attributes when applying optimisation to site selection									
		57	17. Operation limits and conditions	How to establish and substantiate OLCs, how to maintain OLCs to ensure compliance with end-state, how to meet OLCs and assurances that they are being met (especially if operations are not as expected), feedback from other (nuclear) facilities,...									
SITEX WP2 safety topics not covered in SRA Key issues.		58	17. Modifications	Modifications of design, waste acceptance criteria, structures, systems and components (SSCs), operational limits and conditions (OLCs) and operational procedures and methods									
		59	8. Reversibility/retrievability vs. Safety	Common understanding on Reversibility & Retrievability. Benefits and potential adverse effects on safety. Time-frames associated with retrievability and reversibility.									
		60	18. Decommissioning and closure	Programme of closure and decommissioning (including timeframes, formal procedures,...), report after completion of the closure, clearance of material derived from repository decommissioning									
		61	19. Period after closure and institutional cont	Common understanding of the different used terms (monitoring, control, surveillance), planning for post-closure activities (before starting the operational phase), expectations on what is required to release a site from licensing, activities before termination of licence, requirements for marking of a geological repository, rationale for the duration of institutional controls,...									
		62	20. Waste acceptance	Preliminary waste acceptance criteria, how the waste is checked to ensure conformity to waste acceptance criteria, dealing with waste packages that do not conform to waste acceptance criteria									
		63	21. Monitoring (including 17. Operational su	Monitoring programme, expectations for baseline program (timing,...), monitoring to confirm and refine assumptions,...									
		64	22. SC/SA content, scope & objective	Table of content of a SC for each important step of disposal facility development, assessment of technical feasibility, revisions of the SC, traceability and transparency of a SC,...									
		65	31. Indicators and criteria	Criteria for radiological and non-radiological protection of the environment, indicators & criteria for very long time-frames, reference values for complementary indicators, indicators & criteria for performance/robustness assessment									
		66	34. Periodic safety review	Guidance on frequency of PSR, elements to be taken into account in a PSR, Identification and evaluation of safety significance of differences, documentation of PSR and implementation of an action plan									
		67	35. Independent verification	Definition of the term "independent verification", feedback on independent "3rd party" verification (purpose, is it done?, how should it be conducted ?,...)									
		68	Interfaces between safety & security	Compatibility between safety and security requirements									

APPENDIX 2 : SUMMARY OF THE MAIN TOPICS, ASSOCIATED ISSUES AND ACTIVITIES OF COMMON INTEREST

SRA Main Topics and associated issues	Research activities (experiment and/or modelling works)	Horizontal activities: Exchange on practices, develop common positions	Horizontal activities: Develop states of the art	Horizontal activities: Transfer knowledge (eg. training, tutoring…)
Main Topic 1: Waste inventory and source term				
#1. Uncertainty about databases and methodologies used for defining waste inventories (including historical waste)		■		
#2. Evolution of the waste inventory due to possible neutron activation		■		
#3. Understanding of the release processes and speciation of the radionuclides for different types of wastes	■	■	■	■
#4. Waste acceptance criteria		■		■
Main Topic 2: Transient THMBC conditions in the near-field				
#1. Oxidative transient	■			
#2. Chemical conditions induced by metallic and/or cement materials and components	■			
#3. Transients associated with gas production and migration		■		
#3.1 Generation processes and rates of safety-relevant gases other than H2	■			
#3.2 Influence of gas on geochemistry and microbial activity in HR and EBS	■			
#3.3 Gas migration through EDZ and EBS	■			
#4. Co-disposal of waste: interactions between different types of wastes		■		
Main Topic 3: Evolution of EBS material properties				
#1. Heterogeneous behaviour of bentonite components	■			
#2. Behaviour of metallic components	■	■		
#3. Behaviour of cementitious components	■			
Main Topic 4: Radionuclide behaviour in disturbed EBS and HR				
#1. Competition between sorption of radionuclides and other elements from EBS/waste	■			
#2. Influence of organic matter on radionuclide migration	■			
#3. Influence of the thermal transient on RN migration in EBS and HR	■			
#4. Influence of microbial activity on RN migration	■			
#5. Transport of volatile radionuclides in the disposal system	■			

SRA Main Topics and associated issues	Research activities (experiment and/or modelling works)	Horizontal activities		
		Exchange on practices, develop common positions	Develop states of the art	Transfer knowledge (eg. training, tutoring…)
Main Topic 5: Safety relevant operational aspects				
#1. Efficiency of the monitoring system over the operational period	■	■		
#2. Assessment of the risk of fire and explosion	■	■		■
#3. Assessment of the risk of flooding		■		
#4. Influence on long term safety of pre-closure disturbances		■		
Main Topic 6: Managing uncertainties and the safety assessment				
#1. Uncertainties associated with site characteristics		■	■	
#2. Management of uncertainties associated with geodynamics and tectonic movements		■	■	
#3. General methodologies for the safety assessment		■		■
#4. Safety assessment models		■		■
Main Topic 7: Lifecycle of a disposal programme and its safety case				
#1. Methods to review the safety case		■		■
#2. Assessment of the technical feasibility of a geological disposal concept		■		
#3. Evolution of the safety case content with the lifecycle of the disposal programme		■		■
#4. Organization of the pre-licensing phase		■		■
#5. Reversibility and Retrievability		■		
Example of topics for which technical and societal aspects could be investigated:		■		
#6. Application of the optimization principle	■	■		
#7. License of disposal operation	■	■		
#8. Conditions for closure	■	■		
#9. Site selection process	■	■		
#10. Safety culture in the context of geological disposal	■	■		
#11. Intergenerational governance of the operational phase	■	■		