SHARE

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D3.2: Technology assessment/ gap analysis report

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V2	17.06.21	Junaid Ejaz Chaudhry, Christine Georges, Laura Aldave de las Heras, Angelika Bohnstedt, Kurt Van den Dungen	Document to describe the work and results from task 3.2. 'Assessment and comparison of technology/work practices – GAP Analysis/Benchmark'.

Deliverable content

Abstract

The main goal of task 3.2 is to perform gap analysis in technology/ best practices and identify potential actions where further research, developments, and demonstration of innovative solutions could lead to cheaper, faster, and safer future decommissioning options.

The input for gap analysis was mainly gathered in the public online workshop organised by SHARE consortium 1-3 December 2020[1] and open questions from the SHARE survey involving a variety of decommissioning stakeholders(see D2.3 and D2.4). Stakeholders' experience, needs, requirements and opinions were elicited during live online sessions enabling all stakeholder categories to interact and share their experience and expertise on 8 thematic and 71 sub-thematic areas. Moreover, the results compiled from December 2020 to March 2021 to highlight gaps between needs and current best practices or on-going developments and to provide a list of actions to fill these gaps in each of these thematic areas were presented by SHARE consortium at DigiDECOM 2021[2] workshop to gather additional input from the participants and to consolidate the results of gap analysis.

The deliverable report consists of an introduction and 2 main sections:

- Section 2 'Methodology' is dedicated to the description of the approach used to gather input to perform gap analysis and then consolidating the results of the gap analysis.

- Section 3 'Results of gap analysis by thematic areas' is dedicated to the outcomes of the gap analysis in terms of a list of actions for every thematic and sub-thematic area that can impact the identified issues, needs, challenges, and opportunities.

[1] https://share-h2020.eu/2020/12/09/317-people-registered-to-the-public-online-workshop-organized-by-share-consortium-1-3-december-2020/

[2] Synergy with DigiDecom 2021 for a step further towards SHARE Strategic research agenda - Share (share-h2020.eu)

Abbreviations

BIM	Building Information Modelling
DCGL	Derived Concentration Guideline Levels
DTM	Difficult To Measure
E&T	Education and Training
HRM	Human Resource Management
ISDC	International Structure for Decommissioning Costing
I&T	Innovation and Technology
ILW	Intermediate Level Waste
KM	Knowledge Management
LLW	Low Level Waste
NPP	Nuclear Power Plant
PCB	Polychlorinated Biphenyl
PM	Project Management
R&I	Research and Innovation
RP	Radiological Protection
SRA	Strategic Research Agenda
TSO	Technical Support Organisation
TRL	Technology Readiness Level
VLLW	Very Low Level Waste
WAC	Waste Acceptance Criteria
WMO	Waste Management Organisation

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1. Introduction

This report is the deliverable of Task 3.2 of the SHARE project which is focused on providing the assessment and comparison of technologies/ methodologies by performing a gap analysis.

The purpose of this task is to compare the current available technologies and methodologies set out in Task 3.1 (see D 3.1) and possible ongoing and/or under development initiatives, against the research needs highlighted by the questionnaire survey performed in WP2 (see D2.2). As the overall approach of the SHARE project is based on a consultation process with the broader community involved in the decommissioning value chain across the world, specific workshops were organised. In these SHARE workshops, members of the project consortium as chairs guided through the session and encouraged the stakeholders to raise and discuss research needs for 8 thematic and 71 Sub-thematic areas, defined in the questionnaire (WP2) with possible ongoing and/or under development initiatives. The main results of the SHARE survey can be found in the corresponding deliverables D2.4 and D2.5[3].

The goal of the process was to highlight gaps in technology/ best practices and identify potential actions where further research developments and demonstration of innovative solutions could lead to cheaper, faster, and safer future decommissioning options.

As a result, the identified actions are classified by key topics, which will then be prioritised according to the results of the SHARE survey in a Strategic Research Agenda. This will be accompanied by a Roadmap for the next 10-15 years, with the proposal of collaborative schemes for future implementation.

[3] Project Deliverables - Share (share-h2020.eu)

2. Methodology

In order to evaluate the stakeholder's needs and current available solutions, a pragmatic approach towards gap analysis was decided (after balancing the proposed methodology from task 1.2). An overview of progression highlighting the implementation of WP3 is shown in Figure 2-1.

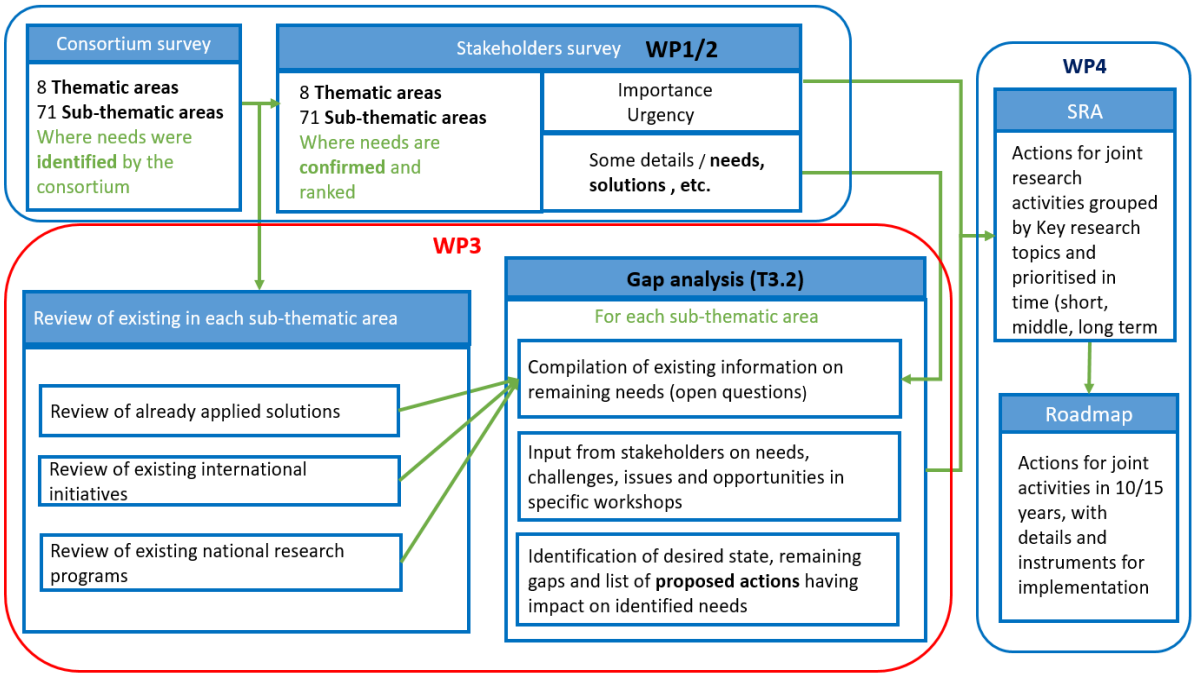

Figure 2-1 Overview of WP3 methodology (highlighted in red)

2.1 Dedicated workshops to support the process in WP3

Task 3.1 which elaborated a review of international best practices and advanced technologies in relation to the thematic areas defined in the survey questionnaire, became the preliminary step for task 3.2. A specific workshop was held in October 2020[4] with the aim to present the review conducted in task 3.1 and to assess together with the workshop participants (experts from the community) the present state of the art. The discussion among consortium members and participants of the workshop assisted to complete the assessment that was required to feed the gap analysis.

A second dedicated public online workshop was held in December 2020[5], within the scope of task 3.2, to receive stakeholders' valuable opinion by firstly investigating with them issues, challenges, and opportunities in research and secondly sharing status and results of ongoing developments. A

[4] SHARE organized a 2-days workshop on international best-practices in nuclear Decommissioning - Share (share-h2020.eu)

[5] https://share-h2020.eu/2020/12/09/317-people-registered-to-the-public-online-workshop-organized-by-share-consortium-1-3-december-2020/

comprehensive community of 317 members from different types of stakeholder registered for the workshop. The distribution of registered participants is given in Figure 2-2.

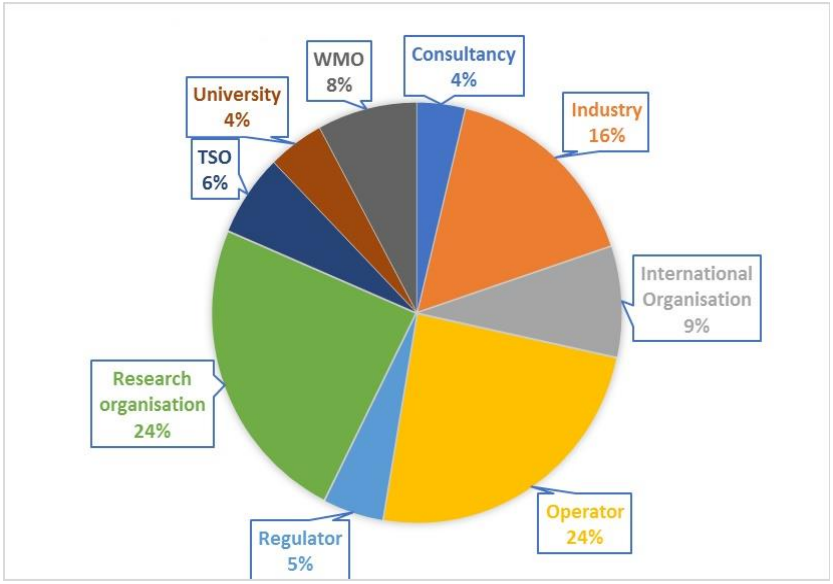

Figure 2-2 Distribution of registered participants by types of stakeholder in the December workshop of SHARE

The worldwide participants from the stakeholder community provided input in a virtual brainstorming post-it sessions conducted by the SHARE consortium team. The methodology followed during these break-out sessions is shown in Figure 2-3.

Figure 2-3 Methodology during break-out sessions

The 71 different break-out sessions were organised according to sub-thematic areas, where a variety of stakeholders participated according to their topics of interest (indicated when registering for the workshop). Every breakout session was divided into different steps. Stakeholders raised various subjects which highlighted the technical and non-technical issues associated with decommissioning procedures. In the first step, stakeholders pointed out numerous needs in research for a particular sub-thematic area. These identified needs were grouped by the session chairs after discussion with the participants accordingly in the next step (step 2, Figure 2-3). For step 3, participants of each breakout session provided insights on current state of available solutions and opportunities against identified needs of step 1. This approach also helped stakeholders to conclude the gap in technology or methodology. These stepwise procedures in different breakout sessions highlighted experience sharing, advancements in technologies, and best practices among the different organisation involved in decommissioning. One example of a virtual brainstorming whiteboard used for December 2021 workshop for post-it breakout sessions is shown in Figure 2-4 (snapshot from the workshop).

Figure 2-4 Virtual board for post-it break-out sessions, screen-shot from December workshop

The data collected during the workshop was afterwards used by the members of task 3.2 for consolidating the knowledge about the available solutions and ongoing activities, for the subsequent gap analysis.

2.2 Gap analysis

Gap analysis was performed to compare the technologies and possible ongoing and under development initiatives, against the results of the needs from the questionnaire survey and research needs highlighted by the stakeholders workshop in October and December 2020 This process focused on gaps in technology/ work practices and identified a list of potential actions that can impact the identified needs by considering research, development, guidance, and demonstration of innovative solutions for every sub-thematic area.

In this regard, all the available data gathered in the scope of Task 3.1, open questions from the survey, and the information collected during December 2020 workshop was introduced in a tabulated form to undergo gap analysis. A structured method considering issues, possible available solutions, and desired state helped to identify certain actions that can be further prioritised to become a part of SRA and Roadmap. The template of the table used for gap analysis is shown in Figure 2-5.

Sub-thematic area	Cluster of needs	Needs, Challenges, Problems, missing	Objectives	Desired state	Possible Solutions	Status of solution	Review from D 3.1	Type of action proposed	Impact/ reason/ outcome of proposed action on:
Q62 Clearance of surfaces and structures (interiors and exteriors)	methodology for clearance to be adapted to different national cases	need for harmonized framework for the clearance of surfaces and structures	Harmonisation and experience exchange for the clearance of surfaces	Dissemination of guidlines and experineces among the stakeholders	reviewing of the IAEA guide WSG- 5.1	EU racomandation RP113 (2000) define the criteria, IAEA WSG- 5.1 (2006) define the objectives, Clearance criteria are defined in Germany. In France, Italy and Spain the methodology is defined case by case IAEA COMDEC Projet and HDCS NEA/CDLM on-going	IAEA COMDEC project reported in the international initiatives available standards in 7.1.1 see references in 7.1.2 about: 1) the study carried out in 2013 by the Swedish Radiation Safety Authority for methods and approach 2) the information available in the EPA website for technologies used to characterize and/or monitor a site before, during or after remediation work	Guidance and dissemination	for harmonisation of criteria for clearance based on the recent experiences

Figure 2-5 Excel table highlighting the methodology for gap analysis

2.3 Proposed actions

Within the scope of the SHARE project, iterative stakeholder involvement was once again prioritised. In this regard, during the DigiDECOM 2021 conference[6], the results of the gap analysis of each sub-thematic area were presented in terms of proposed actions that have an impact on the identified needs. A wider stakeholder community of 222 members of different types registered for the SHARE sessions detained during DigiDECOM conference. The distribution of registered participants by type of stakeholder is given in Figure 2-6.

[6] Synergy with DigiDecom 2021 for a step further towards SHARE Strategic research agenda - Share (share-h2020.eu)

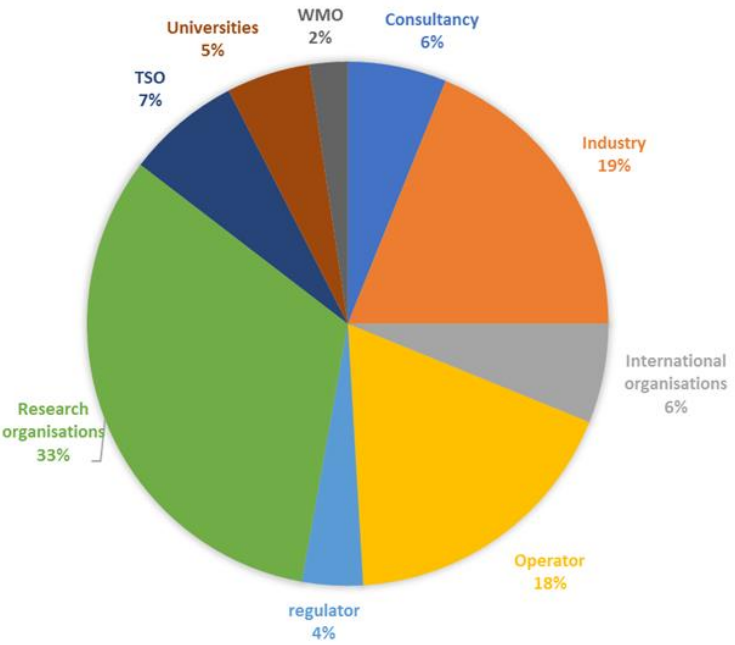

Figure 2-6 Distribution of registered participants by type of stakeholder for SHARE sessions at DigiDECOM conference

The participants of this workshop from the worldwide community of stakeholder approved proposed actions and also provided feedback in terms of new actions focusing on education and training, dissemination and knowledge management in decommissioning. Similarly, to the December workshop, an online tool for interaction with the participants was introduced to consolidate the results of gap analysis in terms of proposed actions. Moreover, stakeholders also provided valuable feedback on some missing actions. The methodology used for this workshop can be seen in Figure 2-7.

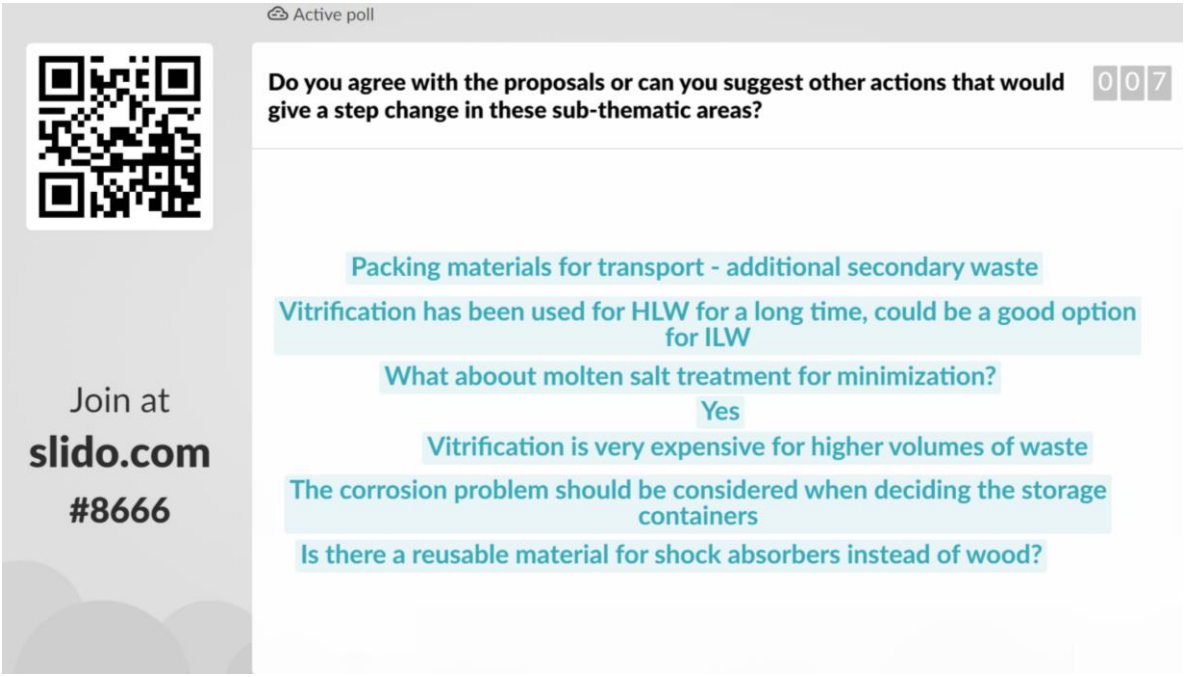

Figure 2-7 Online tool for stakeholders' feedback during SHARE session at DigiDECOM conference

The compiled actions will be further analysed and grouped as key research topics, which will be the basis for the SRA and Roadmap. The detailed synthesis of gap analysis that helped to narrow down important actions having an impact on identified needs for each of the 8 thematic and pointed sub-thematic areas is discussed in detail in the following chapter.

3. Results of gap analysis by thematic areas

The information collected through the survey and through various workshops with stakeholders in each of the sub-thematic areas was analysed by the consortium team and aggregated into clusters representing similar technical and non-technical needs, challenges, and opportunities for Research.

A gap analysis was then carried out, considering, for each of these clusters, the existing solutions and on-going international initiative highlighted by the stakeholders and in the extensive literature survey performed in task 3.1.

The outcome of this gap analysis led to a list of proposed actions to fill the gap, for each sub-thematic area, as presented below, in § 3.1 to 3.8.

Furthermore, the proposed actions were classified in 4 types to provide a better overview;

- **Developments:** actions of R&D, D&D, innovation. This includes preliminary actions like "state of the art", benchmarking or later actions related to industrialisation, commercialisation, and actions to enhance use of the developed product.
- **Networking:** actions to encourage future collaboration and coordination, actions to influence harmonisation of practices, and actions to influence change of practice: e.g. to organise future working groups or platforms, to adapt regulation, legislation, etc.
- **Guidance:** actions to homogenise and elaborate counselling documents to provide advices on best practices in technical and non-technical domains, methodologies, standards, etc.
- **Dissemination:** public information through different channels: e.g. conferences, workshops, E&T, KM, IT tools, etc.

These proposed actions will then be organised by key topic and by type in the future SRA and the corresponding roadmap in WP4.

3.1. Safety and radiological protection

Nuclear safety and the safe management of radioactive waste and spent fuel are national responsibilities. The three main influences on the development of national nuclear safety legislation and practices are:

- The international frameworks, in particular the International Safety Conventions. EU Member States are contracting parties to a number of international safety conventions.

- EU legislation in the field of nuclear and radioactive waste safety, in particular the Directive on Nuclear Safety from 2009 with the amendment in 2014 and the Directive on Management of Spent Fuel and Radioactive Waste from 2011. These two framework directives supplement the Basic Safety Standards Directive on radiation protection.

- The international guidance and regulatory methodologies, such as those promulgated by international bodies like the International Atomic Energy Agency (IAEA), the Nuclear Energy Agency (NEA-OECD), and other groups.

The safety and radiological protection sub-thematic areas are focusing on international harmonisation of safety standards and approaches, development of national regulatory guidance, methods and tools for nuclear safety, and radiological protection approaches and guidance.

Although this thematic area is considered to be a non-technical thematic area, the stakeholders mentioned various concerns that highlighted both technical and non-technical challenges related to these activities. Technical challenges were identified in the Q10 (International harmonisation of safety standards and safety approaches for Decommissioning), Q15 (Methods and tools for nuclear safety) and Q17 (Development of radiological protection approaches and guidance for Decommissioning) sub thematic areas. Non-technical challenges are mainly referred as the development of national regulatory guidance addressed in the Q12 – Q14 (Development/National regulatory guidance for decommissioning: dismantling/clearance/final site release) sub-thematic areas.

The Table 3-1 below summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of Safety and radiological protection.

Note that, in some sub-thematic areas, needs discussed more profoundly in other sessions and/or sub-thematic areas have been also identified.

Table 3-1 : List of proposed actions for 'Safety and radiological protection'

Sub-thematic area	Needs or opportunities	Actions proposed		Type of action
Q10. International harmonisation of safety standards and safety approaches for Decommissioning	International standardisation for safety requirements	Actions to enhance international harmonisation	of national regulatory requirements, including graded approach and more flexibility	Networking
			of WAC in terms of policy and regulation, in coordination with IAEA, NEA, WNA, WENRA, ENSREG, etc.	Networking
	International standardisation for definition of		of clearance criteria for Solid/Liquid/Gaseous rad. materials from decommissioning	Networking

	WAC and Clearance			
Q11. Development / National regulatory guidance for Decommissioning: Preparatory activities	Evaluation of license regulations and alignment of national regulatory guidance to the IAEA standards and guidance	Actions to enhance international and national harmonisation and Guidance in national regulatory framework	to facilitate decommissioning licensing (to shorten the transition phase from operation to decommissioning….)	Networking
	Changes in National framework to facilitate decommissioning licensing		on how to better integrate decommissioning and environmental remediation with waste management	Networking
	Cooperation between different entities, sharing the knowledge		on organisational aspects, knowledge transfer, and training for transitioning to decom (from process to project)	Networking
			better sharing of good practices and networking for development of digital support platforms	Development
Q12. Development /National regulatory guidance for	See Q11			

Decommissioning: Dismantling				
Q13. Development /National regulatory guidance for Decommissioning: Clearance of structures and materials	Complete existing Clearance Criteria for missing radionuclides and Liquid radioactive materials	Guidance	to improve the existing Clearance Criteria (values are missing for some isotopes in DIRECTIVE 2013/59/EURATOM and defined scenario for liquids)	Networking
Q14. Development /National regulatory guidance for Decommissioning: Final site release	Approaches, methods, and tools for the definition of final end-state	Actions to enhance international harmonisation and provide guidance	for selection of the final end-state (incl. definition of scenarios and tools to be used)	Guidance
	Harmonisation of methodology for site release		on methodology for site release	Guidance
		Actions to improve dissemination of guidance	To achieve more flexible regulation in multiple languages, to implement on national level for site release and clearance levels	Dissemination
Q15. Methods and tools for nuclear safety	Emphasis on Good Practices and Procedures for radiological protection.	Benchmarking and guidance	to adopt best practices in decom procedures to uphold safety protocols	Guidance
	New technologies to improve safety, reduce time and enhance stakeholder engagement	Development	of innovative technologies to be used for safety reviews	Development
		Actions to encourage future collaboration and coordination of Research and	to improve acceptability of new technologies by stakeholders	Development

		Innovation (R&I) activities		
Q16. Methods and tools for conventional industrial safety	See need in Q17 'integration of the RP approaches and conventional protection approaches'			
Q17. Development of radiological protection approaches and guidance for Decommissioning	Practical implementation of protective measures for radiological and non-radiological (e.g., chemical) risks	Development	of modern protective tools for combined management of multiple hazards (e.g., asbestos/alpha)	Development
		Homogenisation of regulation	for mixed hazards (asbestos/alpha) and for management of mixed waste, materials and structures in terms of radiological protection	Networking
	Training and education on RP and digitalisation	Guidance and Development	to adapt RP procedures from operation approach to decommissioning	Guidance
			to enhance the use of digital tools/develop scenarios	Development
	Integration of RP and conventional protection approaches for management of mixed waste, materials and structures	Guidance	for new practical programmes to disseminate approaches for management of mixed waste, materials and structures	Networking
	Cross industry collaboration and learning from other industries	Actions to encourage future collaboration	among industries for planning initiatives and exchange of learnings. Addressed also in 3.3 'Human resource management'	Dissemination

	Need to include a societal, political, psychological, historical and economic factors perspective	Coordination with NEA and IAEA *(Transversal topic to be addressed in 3.1, 3.2 and 3.3)*	to identify how human sciences can be of help to decommissioning in the future, on the basis of pragmatic topics/ situations, etc. (socio-economic and legislative consideration)	Networking

3.2. Project management

For decades, nuclear projects were mainly aimed at building facilities such as NPPs, fuel cycle facilities, waste management storage facilities etc. From the 90s', decommissioning has triggered new challenges in terms of project management and planning as well as costing. Based on its Member States growing experiences and feedback, the international decommissioning community has identified these domains as of utmost importance when it comes to the achievement of decommissioning projects as well as effective decommissioning strategies.

The thematic area Project Management is divided into different sub-thematic areas addressing the challenges linked to decommissioning project management. They are covering methodologies and software tools for decommissioning strategies, for project management and performance monitoring; Supply chain management; Methodologies and tools for cost estimation; New technologies in particular when it comes to digital transformation and which tools are best to use; New technologies and communication techniques to ensure successful information sharing with civil society.

The Table 3-2 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of 'Project management'.

Table 3-2 : List of proposed actions for 'Project management'

Sub-thematic area	Needs or opportunities	Actions proposed		Type of action
Q19. Methodologies and software tools for comparison of alternative decommissioning strategies components (reactor vessel internals, etc.)	Strategy and scenario analysis	Guidance	to choose cheaper and safer scenarios for decommissioning	Guidance
		Guidance	on best tools to choose cheapest and safest scenario	Guidance
	Interoperability of all software used in decommissioning from Strategy and scenario analysis to monitoring on site	Guidance	on existing tool in and out nuclear industry	Guidance
		Standardisation	to enhance interoperability between IT tools	Development
		Development	to enhance interoperability between IT tools	Development
	Oversight	Actions related to coordination	with SHARE project	Networking
		Guidance	to address uncertainty	Guidance
		Developments	for long term data storage	Development
Q20. Methodologies and software tools for project management and performance monitoring	Expectations for capabilities of PM tools	Guidance	on best tools for PM dedicated to Decommissioning	Guidance
	Use of PM tools within the organisation	Development	to take into account decommissioning specificities	Development
			BIM tools	Development

	Asset data and information management	Enhance use of	ISDC among Decommissioning projects	Development
			Virtual training	Development
		Developments	to better address risk management	Development
Q21. Tools for data collection in the field (e.g. for work monitoring)	Data collection technology	Enhance use of	new technologies for characterisation and inventories	Development
			IT tracking system for waste management	Development
			IT tools to monitor logistics flows	Development
		Development	to improve communication with other PM softwares	Development
	Strategic approach	Enhance use of	digital methods for decommissioning	Development
		Guidance	on system approach to digitalisation	Guidance
Q22. Digital transformation in decommissioning (big data, business intelligence)	Data acquisition	Enhance use of	modern data collection techniques	Development
	Data and information management	Development	of electronic data management	Development
	Information application and methods	Guidance and enhance use of	VR, 3D modelling, and digitisation for decommissioning tasks	Guidance
Q23. Supply chain management for decommissioning	Enabling the supply chain	Enhance use of	immersive room to simulate scenarios and train	Development
		Developments	of database of qualified suppliers	Guidance
			for analysis of risk and how shared (owner/contractor)	Guidance

	International standardisation and knowledge management	Standardisation	on definition of project manager in the field of Decommissioning	Dissemination
			towards role definitions (responsibilities) for all, not just Project Manager	Dissemination
		Enhance use of	homogenised practices in the field of waste management from decommissioning	Guidance
	Waste management	Development	towards waste traceability	Development
Q24. Methods and tools for communication (public)	Communications with local community	Development	communication tools to explain what is decommissioning (when site visits, etc.)	Development
	Information and tools for communication			
	General communication plan			
	Need to include a societal perspective	Guidance	on stakeholders involvement	Guidance
	Addressing public attitude toward the nuclear industry			
		Actions related to education	to engage youth	Dissemination
Q25. Methodologies and guidance for cost estimation	Optimisation tools	Guidance	on cost methodology (update) with all costs (engineering , waste management, etc.) and not only for NPPs also to make benchmarking easier	Guidance
	Waste			
	Benchmark	Coordination	with NEA CDLM/ Expert Group on Costing for Decommissioning of Nuclear Installations and Legacy Management (EGCDL)	Guidance
	Methodology			

<table>
<tr><td rowspan="2"></td><td>Better costing tools for decommissioning</td><td rowspan="2">Coordination</td><td rowspan="2">with NEA and IAEA on dissemination of ISDC hierarchical structure among decommissioning projects and extension of ISDC</td><td rowspan="2">Dissemination</td></tr>
<tr><td>Funding estimations</td></tr>
<tr><td rowspan="2">Q26. Software for cost estimation (partly discussed in other sessions)</td><td>Data sharing</td><td colspan="3" rowspan="6">See Q25</td></tr>
<tr><td>Flexibility</td></tr>
<tr><td>Q27. Development of mechanisms for cost benchmarking (discussed in other sessions)</td><td></td></tr>
<tr><td rowspan="4">Q28 Methods and tools for sensitivity and uncertainty analysis in cost estimation

(partly discussed in other sessions)</td><td>Early definition of risks and challenges</td></tr>
<tr><td>Optimised tools</td></tr>
<tr><td>(International) peer-review</td></tr>
<tr><td>Uncertainty</td></tr>
</table>

3.3. Human resources and management

The transition of nuclear facilities from operations toward decommissioning is a crucial stage that requires an efficient workforce, in general composed by novel personnel not knowledgeable beforehand of a specific nuclear site. In addition, each decommissioning project is also specific. Therefore, the initial SHARE survey addressed four intertwined aspects related to human resources & management, namely: 1) organisational models for decommissioning, 2) knowledge management aspects, especially in terms of knowledge preservation and transfers from operating personnel toward decommissioning personnel, 3) general education for decommissioning, and 4) methods and tools for task specific training. Indeed, aligned with a staged approach to decommissioning, these four aspects

need to be addressed at once in a holistic way by the decommissioning organisation(s), in order to streamline the planning and implementation of the decommissioning stage.

The complexity of human resources and management (HRM) was addressed in SHARE online international workshops involving a variety of decommissioning stakeholders and finally reach a consensus related to the four HRM sub-thematic areas mentioned above.

It is worth mentioning that, even though HRM is considered a non-technical issue, participants addressed technical aspects related to knowledge management (e.g. data interoperability), as well as to task-specific training (e.g. IT tools, immersive simulators). These technical aspects influence both intra-organisational and inter-organisational human resources management and harmonisation.

The Table 3-3 presents the consolidated and synthesised stakeholder ideas and viewpoints, categorised into “Needs or Opportunities”, “Actions proposed”, and “Type of action” that can affect these needs for all four sub-thematic areas of ‘Human resources and management’.

Table 3-3 : List of proposed actions for ‘Human resources and management’

<table>
<tr><th>Sub-thematic area</th><th>Needs or Opportunities</th><th colspan="2">Actions proposed</th><th>Type of action</th></tr>
<tr><td rowspan="3">Q30. Organisation models (staff & resources)</td><td>Organisational transformation from operations toward decommissioning needs per decommissioning stage</td><td>Coordination between EU, IAEA and NEA to check if need to revise existing documents and to disseminate information</td><td>on organisational transformation from operations toward decommissioning (e.g. in the case of Transfer of license or after a prolonged period of deferred dismantling, etc.)</td><td>Guidance</td></tr>
<tr><td rowspan="2">Inter-organisational best practices for engagement between actors</td><td>Coordination between EU, IAEA and NEA to check if need to update existing documents and to disseminate information</td><td>on inter-organisational best practices for engagement between actors (e.g. regulators and contractors in the project organisation, "Float approach" in contracting, with a global view based on economic aspects, availability of companies, and common market, etc.)</td><td>Guidance</td></tr>
<tr><td colspan="3">see 3.1 ‘Safety and radiological protection’</td></tr>
</table>

		Establish common rules and requirements	to provide access to international decommissioning markets	Networking
	Intra-organisation decommissioning mission	Coordination between EU, IAEA and NEA to check if need to update existing documents and to disseminate information	on intra -organisational best practices to achieve more efficient organisation (multi-functional decommissioning team-based structure, alternatives to department structure, etc.)	Guidance
Q31. Methods and software tools for knowledge management (e.g. competence preservation)	Knowledge capturing & sharing forms/formats (text, video, audio, etc.)	Actions to harmonise	knowledge bases for future end users in decommissioning operations (through knowledge management (KM) formats, data interoperability, information hierarchy, optimisation of knowledge transfer processes, integration of security standards in the methods and software, etc.)	Guidance
	Data & software interoperability: past, present, future	Benchmark and dissemination	on new methods & tools in KM for knowledge capture & preservation	Guidance
	Compliance with regulatory & security standards (national & international)	Actions to coordinate	KM efforts internationally	Guidance
	Identifying & preserving knowledge	Establish protocols	for knowledge collection during operation phase that will be useful during decommissioning	Guidance

Q32. General education for Decommissioning	Secure young workforce: Attract & Motivate	Actions related to Education and training	to secure, attract, and motivate young workforce in D&D	Development
	Collaborations	Actions to enhance cooperation	related to education and training between industry, universities and research organisations; information should be integrated in the overall KM	Development
	Knowledge retention & transfers	Benchmark best practices	for local and international knowledge retention and transfers	Guidance
	Harmonised education for decom workforce	Actions to harmonise	levels of education required for decommissioning (certifications for specific skill sets, etc.)	Networking
	Mobility support	Action to enhance	international mobility (provide internships & certifications, etc.)	Development
Q33. Methodologies and tools for task specific training	Simulation technologies for task specific training	Actions to enhance use of	IT tools for costing and waste management (benchmark features & benefits of immersive simulation tools for task specific training, especially for radiation protection, etc.)	Development
	Standards & Regulations for task specific training methods & tools	Actions to enhance use of	immersive training methods & tools (through recognition, standards, certifications, etc.)	Development

	Training needs	Identify priorities	in emerging training needs & requirements in decommissioning	Development
	Organisational R&D needs	Actions to promote	education and training among employees, sharing between countries & organisations; cooperation between actors involved, industrial partners, etc.	Development

3.4. Characterisation

Characterisation plays an important role in the decommissioning of nuclear facilities. It is the basis for radiation protection, identification of contamination, assessment of potential risks, cost estimation, planning and implementation of decommissioning. Characterisation is relevant in all phases of the life cycle of a nuclear installation, albeit with different levels of detail and with differing objectives. The following characterisation phases can be distinguished: pre-operational characterisation; characterisation during operation; characterisation during the transition phase (after final shutdown before initiation of dismantling); characterisation during dismantling (including remediation and decontamination); and characterisation to support the final status survey for site release. The most comprehensive characterisation campaigns are usually carried out during the transition phase in preparation for implementation of dismantling activities, or during the dismantling phase where systems, structures, components, and buildings must be characterised for decisions regarding the extent of decontamination, application of appropriate dismantling techniques, identification, classification, treatment of radioactive materials, etc. The final status survey on the site must consider the possibility of subsurface contamination, which may lead to radionuclide transfer into ground water and surface water bodies.

In the thematic area of characterisation, the different sub-thematic areas based on the question numbering provided in the SHARE survey are addressed. In addition, some other sub thematic areas related to the characterisation but belonging to others of the 8 thematic areas such as dismantling, environmental remediation and site release and radioactive waste management are considered in this chapter. There are highlighted technical issues in the field of characterisation, as well as non-technical issues such as regulatory, standardisation, safety, education and training and dissemination.

The Table 3-4 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of ‘Characterisation’.

Table 3-4 : List of proposed actions for 'Characterisation'

Sub-thematic area	Needs or opportunities	Actions proposed		Type of action
Q35. Methodology for historical site assessment	Historical Information Data Management (Digital Archive and Georeferenced information)	Development	on innovation and technology related to digital methods for Decommissioning	Development
Q36. Inventory assessment (Radiological and non-radiological)	Modelling and calculation methods	Guidance	on enhance and improve the use of models	Development
	Radiological inventory techniques	Guidance	on methodology for the radiological inventory and level of details required.	Guidance
			on inventory methodology based on past incidents, current measurements. Use of appropriate equipment	Guidance
Q37. Characterisation of activated components and areas (Metal)	Large metallic components & Complex geometries	Development	on technologies to map activity on large metallic components	Development
			on automation of the combined techniques	Guidance
	In-situ characterisation in high dose rate environments	Guidance	on benchmark on-going developments	Development
	Difficulties to measure alpha and beta radionuclides (in situ, ex situ)	Development	on methodologies and technologies for DTM including automation (R&D and I&T)	Development

Q38. Characterisation of activated components and areas (Concrete)	Difficulties to measure alpha and beta radionuclides (in situ, ex situ)	Development	on methodologies and technologies for DTM including automation (R&D and I&T)	Development
	Methodologies for contamination in depth / 3D Hot spots	Development	on methodologies and technologies for in depth	Development
	Methodology of mixed waste with concrete	Development	on methodologies and technologies for characterisation of mixed waste with concrete	Development
Q39. Characterisation of activated components and areas (Graphite)	No specific needs			
Q40. Technologies for hard to access areas (high walls, embedded components, harsh environment…)	Robotics, including drones and sensors	Development	towards industrialisation	Development
		Guidance	to enhance the use of robotics, drones and sensors	
		Non- Technical Transversal actions	actions related to education and training. actions related to regulation (dialogue with regulators)	
Q41. Development of modelling and simulation software for characterisation of irradiated components	Model simplification and validation	Guidance	on methodology, benchmarking and dissemination on models including validation	Guidance

Q42. Standards for statistical sampling	Guidelines	Guidance	on methodologies and dissemination	Guidance
Q43. Geostatistical software applications	No specific needs	Non- Technical Transversal actions	actions related to education & KM	Dissemination
Q44. Sample analysis technologies	Fast, cheap, and straightforward methods for sample analysis	Development	for improvements of existing technologies	Development
		Benchmarking	for existing technologies	
Q45. Alpha and beta non-destructive measurements	Fast, cheap, and straightforward methods for DTM	Development	on methodologies and technologies for in situ DTM determination	Development

Sub thematic areas related to the characterisation field from other thematic areas

Sub-thematic area	**Needs or opportunities**	**Actions proposed**		**Type of action**
Q52. Handling, segregation and loading of segmented elements and secondary waste	Automation in segregation of waste	Development	towards innovation of autonomous systems for segregation and handling	Development
Q53. In situ Radioactive Waste	Indoor positioning systems	Guidance, optimisation and enhancement of use	on methodology, benchmarking, and dissemination	Development

characterization and segregation	In situ alpha characterisation	Development	for improvement on existing technologies	Development
	Characterisation and vision systems to accurately identify waste items	Development	towards innovation of autonomous systems	Development
	Integrated systems	Development	of innovative technologies having integrated systems allowing both chemical and radiological characterisation	Development
Q55.Dismantling of surface-contaminated piping and small components	Characterisation of residual solvents in piping and vessels	Guidance	on methodology for the characterisation of residual solvents in piping and vessels on benchmarking and dissemination	Guidance
Q62. Clearance of surfaces and structures (interiors and exteriors)	Improvements and automation of characterisation methods to optimise clearance	Development	towards research and innovation for automated characterisation systems for clearance	Development
Q63. Characterisation methods and technologies to identify subsurface contamination	Improvements of characterisation techniques for underground contamination	Development	in the technology for characterisation related to low, very low, and underground contamination	Development
	On-line characterisation during remediation and clean-up	Development	on automation technologies used during remediation and clean-up	Development
		Guidance	on dissemination (best practices)	Guidance

Q67. Methodologies and techniques for final release survey of the Site	Characterisation and release of remaining underground structures	Guidance	on methodologies to characterise the underground remaining structures	Guidance
Q83. Characterisation and survey of containerized radioactive waste	Characterisation for segregation including legacy waste	Development	on technology of mobile systems to characterise containerised RW	Development
			on technologies and methodologies for characterisation of unconventional legacy waste. Integrated systems.	Development

3.5. Site preparatory activities

The transition from an operating facility to the execution of the dismantling phase is significant in every decommissioning project. A variety of site preparatory activities may be planned and organized in various ways depending on considered decommissioning strategies and physical and radiological status of the nuclear facility after its routine operation is over. Typically, these activities include technical activities (defueling of reactors, retirement of equipment and systems, radiological and waste characterization, operational waste treatment, internal system decontamination, and removal of minor components), regulatory framework and authorisation for decommissioning, dialogue with external stakeholders, and organisational transitions. The actions taken at that time will pave the way to efficient and cost-effective decommissioning by eliminating, reducing or mitigating hazards, minimizing uncertainty and maintaining steady progress.

In this thematic area, different sub-thematic areas based on the question numbering provided in the survey questionnaire are addressed. These chosen sub-thematic areas are majorly dealing with site preparatory activities which comprises of conversion of auxiliary systems for decommissioning, preparation of infrastructures including storages and buildings for decommissioning, and internal system decontamination.

The Table 3-5 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of ‘Site preparatory activities’.

Table 3-5 : List of proposed actions for 'Site preparatory activities'

Sub-thematic area	Needs or opportunities	Actions proposed	Type of action
47.Adaption of auxiliary systems for decommissioning (ventilation, electrical, monitoring, etc.)	Automation in monitoring	Linked to Q52 and discussed in 3.4 'Characterisation'	
48.Preparation of infrastructures and buildings for decommissioning (storages, capabilities for material sorting and treatment...)	Mobile infrastructures	Action proposed in Q73 is related to mobile infrastructures and discussed in 3.8 'Radioactive waste management'	
49.Systems decontamination (internal)	Handling of liquid waste	Discussed in Q75 and Q76 as a part of 3.8 'Radioactive waste management'	

3.6. Dismantling technologies

Dismantling of nuclear facilities entails activities allowing to remove and to optimize the volume of waste (vessels, tanks, piping, pumps, etc.) before transportation to storage or disposal sites. They precede the demolition tasks of a building that includes scarification of contaminated concrete surfaces and then reducing the heavily reinforced concrete structures to rubble. Different dismantling techniques are chosen based on: radiological criteria, availability of suitable equipment, complete knowledge of the problem, structured timings, and cost-effectiveness of the proposed solutions. Meanwhile, the use of more efficient technologies and processes could reduce the decommissioning project time schedule and therefore reduce the staffing costs acquired throughout the decommissioning project life. In this regard, developments are being done to automate and introduce remotely-operated equipment and robotics for dismantling process. Such systems can offer a substantial benefit with respect to worker safety and exposure reduction.

In this thematic area, different sub-thematic areas based on the question numbering provided in the master questionnaire are addressed. These sub-thematic areas are majorly dealing with dismantling technologies which comprises of segmentation of large irradiated metallic components, cutting of piping and small components, different decontamination techniques for metallic as well as concrete structures, demolition of large reinforced structures, introduction of robotics and remote control tools

for dismantling, and more importantly management, handling, and segregation of segmented elements.

The Table 3-6 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of 'Dismantling'.

Table 3-6 : List of proposed actions for 'Dismantling'

Sub-thematic area	Needs or opportunities	Actions proposed		Type of action
Q51. Segmentation of large irradiated metallic components (reactor vessel internals, etc.)	Segmentation strategy optimisation	Guidance	for the selection of segmentation strategy for large irradiated metallic components	Guidance
		Development	of pre-segmentation strategy (intended towards decontamination	Development
	Innovative remote autonomous techniques	Actions to enhance	confidence in safety authorities and operators to use innovative remote autonomous tools for RPV segmentation	Development
		Development	to integrate remote control dismantling techniques with 3D models & simulations	
		State of the art	on long reach manipulators with greater dexterity	
		Guidance	to compare life operation of equipment to assess the equipment life vs cost	
Q52.Handling, segregation and loading of segmented elements and secondary waste	Discussed in 3.4 'Characterisation'			

Q53. In situ Radioactive Waste characterization and segregation	Discussed in 3.4 'Characterisation'			
Q54. Segmentation of large surface-contaminated components	Segmentation strategy optimisation	Benchmarking	for selection of segmentation strategy for large surface contaminated components that are compatible with decontamination techniques	Guidance
	Secondary waste minimisation	Guidance	to prefer cheaper and safer technology that minimises the secondary waste during segmentation	Guidance
Q55. Dismantling of surface-contaminated piping and small components	Innovative cutting techniques	Development	in technology for already existing pipe cutting technologies that provide secondary waste minimisation and good rate.	Development
			of technologies and methodologies for hard to access piping for surveying and segmentation	Development
			towards industrialisation of Electrochemical cutting to take into account DECOM specificities.	Development
Q56. Segmentation of interior concrete structures (e.g., bioshield)	Improvements in concrete segmentation techniques	Benchmarking	for already implemented segmentation technologies for interior concrete structures and biological shield	Guidance
Q57. In situ decontamination of building surface (concrete)	Techniques that limits secondary waste	Benchmarking	for technologies and methodologies for in-situ decontamination with good rate and minimised secondary waste production	Guidance

	Inventory assessment before the selection of technique	Development	of scanners and detectors to select best approach for decontamination	Development
Q58. Management (characterisation, decontamination, removal) of radiological embedded elements	Management of embedded waste	Guidance	on separation of embedded elements (metal in plastic) for the final outlet (from the regulator)	Guidance
	Technologies for characterisation of embedded radiological elements	Discussed in Q40 as a part of 3.4 'Characterisation'		
Q59. Demolition of large, reinforced concrete structures	Safety reference	Benchmarking	for the safer techniques for demolition of large structures with reinforced concrete.	Guidance
		Guidance	for using remote demolition that provides worker safety.	Guidance
	Innovation and improvements in Laser technology	Benchmarking	for laser technology considering secondary waste minimisation and efficiency	Development
		Development	in laser technology by considering micro melting phenomenon	
Q60. Robots and remote controlled tools for dismantling	Modular and mobile solutions	Enhance use of	multi-purpose modular and mobile systems for different dismantling tasks	Development
	Updating robotic database	Development	for easy access to database that provides information on evaluated robotics for different tasks in decommissioning	Development

	Digitisation for advancement in systems	Development	towards digitisation for advance systems to enhance interoperability between different IT tools	Development
	Robotic solutions for specific circumstances	Benchmarking	for efficient remote cutting technologies	Guidance
		Development	on technologies and methodologies for hard to access areas with betterment in tele-operated remote arms	Development
	Safety and standard concerns	Standardisation	on the use of robotic systems for dismantling by providing safety cases to enhance confidence for regulatory authorities and operators	Guidance
			of verification and demonstration for robotics (best approach)	Guidance
		Development	of testing methodologies for robotics in mock-up	Development
Q71. Mechanical Radioactive material decontamination	Improvements in Laser decontamination	Benchmarking	for laser technology considering secondary waste minimisation and efficiency	Development
	Remote systems for decontamination	Benchmarking	for remote systems with integrated characterisation and decontamination	Development
		Guidance	on life-cycle of decontamination systems	
Q72. Electrochemical Radioactive material decontamination	Innovation in electrochemical decontamination technique	Development	toward research in Electrochemical decontamination technique	Development
	Impact optimisation on waste forms	Guidance	on waste forms from Electrochemical decontamination according to WAC's	

Q74. Radioactive material treatment processes (concrete)	Efficient Decontamination techniques	Benchmarking	for decontamination techniques with implementation of remote operations	Development
		Guidance	to assess the failure mode and impact on performance of dismantling task to maximise life expectancy of a machine	

3.7. Environmental remediation and site release

Environmental remediation and site release involve different technologies and methodologies with the final goal of returning a site to the conditions that prevailed before the contamination and in compliance with the national legal and regulatory requirements. The release from the regulatory control may be unrestricted or restricted, often termed “green field” or “brown field”.

In this thematic area, different sub-thematic areas based on the question numbering provided in the survey questionnaire are addressed. These sub-thematic areas are dealing with methodologies and techniques for clearance of surface and structure, characterisation methods for sub surface contamination, modelling and statistical tools to analyse contaminant transport in subsurface soil and groundwater, methodologies and techniques for final release survey of the site and related tools for statistical analysis and management of survey data, soil remediation technologies and remediation of contaminated groundwater.

The highlighted technical challenges are related to characterisation methods and technologies used during the different phases of the process (from the first problem definition phase to the final release phase) and to the technologies and methodologies applied during implementation phase to remove/reduce to acceptable level the contamination and non-technical challenges are mainly referred to the national legal and regulatory requirements that play a relevant role in the planning and execution of the activities and in the definition of the final end-state of the site.

The Table 3-7 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of ‘Environmental remediation and site release’.

Table 3-7 : List of proposed actions for 'Environmental remediation and site release'

Sub-thematic area	Needs or opportunities	Actions proposed		Type of action
Q62. Clearance of surfaces and structures (interiors and exteriors) ***Note: Also discussed in 3.4 'Characterisation'***	methodology for clearance to be adapted to different national cases	Guidance and Dissemination	for harmonisation of criteria for clearance based on the recent experiences	Networking
		Development	of international guidance of site release criteria (DCGL) for site and building reuse and recycling of demolishing building structure	Guidance
Q63. Characterisation methods and technologies to identify subsurface contamination ***Note: Also discussed in 3.4 'Characterisation'***	models for release of underground structures	Development	of models and harmonisation among stakeholders for release of underground structures	Development
Q64. Modelling and statistical tools to analyse contaminant transport in subsurface soil and groundwater	Improvements in accuracy of predictive modelling	Development	of digital tools to facilitate the predictive modelling for contaminant transport, radionuclide behaviour in longer term and underground contamination	Development
	Improvements in model building and long-time follow-up	Dissemination	of experience exchange among the stakeholders on models used	
Q65. Soil remediation technologies (washing, bioremediation,	Multi criteria analysis to optimise the decision-making process	Development	of multi criteria analysis considering cost, end state and environmental protection, to optimise the decision making towards soil remediation technologies	Development

contamination fixing)	Improvements in the capabilities of the soil remediation technologies	Development	to improve the practical implementation reducing time and costs	Development
	Integrations of characterisation technologies and remediation technologies	Coordination	between the market stakeholders (different suppliers) for characterisation and remediation technologies	
	network for implementing the test cases and sharing info	Benchmarking	between the stakeholders for harmonisation in using soil remediation technologies	
Q66. Remediation of contaminated groundwater (radiological)	Technologies to face post accidental contamination	Development	of large-scale technologies or mixed technologies (both for remediation and prevention) to face with a post accidental contamination	Development
	Technical solutions for ground water remediation	Benchmarking	of technologies for: remediation and prevention of any contamination or the spread into the environment	
	Improvements in technology for on-line radiological monitoring of groundwater	Development	of on-line technology for a long-term monitoring of groundwater	
	Bioremediation techniques	Development	of bioremediation techniques for groundwater remediation	
Q67. Methodologies and techniques for final release survey of the Site	Improvements in methodologies and techniques for final release survey of the Site	Dissemination	of experience exchange among the stakeholders to get greater harmonisation of processes	Guidance
		Guidance	on the definition of final end-state or the future of the site	

Note: Also discussed in 3.4 'Characterisation'				
Q68. Tools for statistical analysis and management of survey data for site release	Improvement in tools for statistical analysis and management of survey data for site release	Benchmarking and guidance	of existing IT tools available for statistical analysis and management of survey data for site release	Guidance

3.8. Radioactive waste management

This chapter, complementary to chapter 3.6 is addressing management of radioactive waste from decommissioning, once removed during dismantling operation; this includes different activities like processing, storage and transportation from the generation to its disposal or to its release and recycling, but not including final waste disposal.

The overall goal of this set of actions proposed is the optimisation of waste management in terms of categorisation, volume and activity, in coherence with dismantling strategies, in a holistic waste led approach.

The Table 3-8 summarised the main needs, opportunities, list of actions proposed, and type of action for each sub thematic area in the field of 'Radioactive waste management'.

Table 3-8 : List of proposed actions for 'Radioactive waste management'

Sub-thematic area	**Needs or opportunities**	**Actions proposed**		**Type of action**
Q70. Management routes for materials including radioactive waste streams	IT tools for decision making	Sate of the art, development if needed + Guidance	on IT tools to help operator when choosing routes for waste during preparation phase of decommissioning	Development
	Waste minimisation opportunities	Actions to enhance	waste minimisation and optimisation during dismantling operations (see also §3.6)	Development

	Improve route for secondary waste streams to enhance local use of internals' decontamination	Development	of simpler and cheaper processes to decontaminate internals during decommissioning: decontamination processes and encapsulation processes, etc. providing alternatives to existing processes leading to encapsulation of secondary waste in resins (highly contaminated Resins are not compatible with WACS)	
	Open routes for waste not answering to present WACS	Actions on regulations to improve	management of contaminated waste mixed with Asbestos and PCBs from decommissioning to disposal (see also Q86)	Networking
		Technical and non-technical actions	to improve management of Graphite mixed waste from decommissioning to disposal	Development
		Technical and non-technical actions	to improve management of contaminated toxic liquid and materials from decommissioning to disposal (see also Q86)	Development
		Identify	other needs and coordinate with ROUTE and PREDIS	Development
	International harmonisation on management of waste transportation, standardisation and packaging	Actions to enhance harmonisation	of practices in VLLW management (metal, concrete , etc.) regarding clearance and acceptance criteria	Networking
		Actions to define strategy and promote	international sharing of facilities for treatment or storage of waste from decommissioning	Networking
		Actions to enhance harmonisation	of practices in packaging (transport, storage, disposal)	Networking

	Industrial implementation of emerging technologies for waste treatment	Actions to encourage use of new developments	to better manage waste flows from production to disposal (IT tools and other emerging technologies)	Development
		Development, industrialisation and promotion of	emerging solutions at lab scale for waste treatment (to optimise volume of waste to disposal)	Development
Q71. Radioactive material decontamination (mechanical)	Discussed in 3.6 'Dismantling'			
Q72. Radioactive material decontamination (electrochemical)	Discussed in 3.6 'Dismantling'			
Q73. Radioactive material treatment processes (metals)	Harmonisation of practices	Actions to enhance harmonisation	of practices for treatment of VLLW metallic waste, including recycling	Networking
	Guidance	Guidance	to enhance co-ordination between waste producers and operator of melting system (on requirements, on decontamination place, etc.)	Guidance
	Simplify the handling of secondary waste from processing	Developments	to simplify the handling of secondary waste from decontamination, fusion or other processing for metallic waste from decommissioning	Development
		Guidance	on choice of processes for metallic waste treatment, including secondary waste management	
Q74. Radioactive material treatment	Harmonisation of practices	Actions to enhance harmonisation	of practices for treatment of VLLW concrete waste, including recycling	Networking

processes (concrete)	Knowledge on long term behaviour	R&D	to demonstrate long term behaviour of irradiated/ activated cement from decommissioning	Development
Q75. Radioactive material treatment processes (aqueous liquids)	Improve management of liquid waste with specific contaminants (Tritium, 14C, Boric acid, colloids, mixed waste, etc.)	Guidance	on existing routes and methodologies for management of liquid waste with specific contaminants (Tritium, 14C, Boric acid, colloids, mixed waste, etc.)	Guidance
		State of the art	to identify needs for developments for treatment of specific contaminants in liquid waste	
		Actions to enhance harmonisation	of practices in the regulation for authorised release level in operation and in decommissioning phases (for Boron, Tritium, etc.)	Networking
	Management of small volumes of diverse wastes	State of the art and Guidance	on use of mobile devices for treatment of liquid effluents	Development
	Management of secondary waste from treatment of liquid waste	Developments	to increase TRL level and use more widely mineral adsorbents to replace organic resins for treatment of contaminated aqueous liquids (adsorbent directly disposable; e.g. trapping radionuclides under radiations, etc.)- see also Q70	
Q76. Radioactive material treatment processes (non-aqueous liquids)	Optimise management of organic liquids	State of the art, comparative analysis and Guidance	of various options for liquid organics including local mobile solution versus big centralised facilities	Development
	Implement solutions developed in	Share data and demonstrators	for already developed processes for treatment of organic liquids e.g. plasma	

	laboratories with engagement of all actors (for all waste, not only organics)		under water, etc. and long term performances of innovative conditioning matrix	
		Benchmarking	in oil/gas or hazardous waste sector	
		Coordination for Guidance	on strategies for organic liquid waste management (with all actors along the value chain (and ideally with international experts) to brainstorm and propose solutions and future action plan; Note: in and out of waste management	Guidance
Q77. Radioactive material treatment processes (organic materials)	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics)	State of the art, techno- economical comparative analysis and Guidance	on various options for solid organics including local mobile solution versus big centralised facilities depending on waste streams (variety, quantity, activity, etc.)	Development
		Benchmarking	in oil/gas or hazardous waste sector	
		Share data and demonstrators	for already developed processes for treatment of solid organic and long term performances of innovative conditioning matrix	
Q78. Radioactive material treatment processes (VLLW)	Improve management of VLLW waste	Actions to enhance harmonisation	of practices in VLLW management	Networking
Q79. Radioactive material treatment processes (LLW)	Provide guidance on Decision making on process/	Facilitate decision making, Guidance on methodologies and strategies	in the choice of treatment process for LLW waste (efficiency, de-categorisation, volume	Guidance

	Treatment and categorisation		reduction, compliance with WAC, etc.	
	Management broken packages	Guidance	to improve management of broken packages	Guidance
	Ashes produced during thermal processes (LLW and ILW)	Development	of optimised processes for management of ashes produced during thermal processes of ILW.	Development
Q80. Radioactive material treatment processes (ILW)	Management of small waste quantities	State of the art and guidance + development if needed	for small facilities / mobile etc. for treatment of small quantities of waste (see liq. Above Q75 + resins, etc.)	Development
	Impact of microbiological activity on waste stored in open ponds	R&D and guidance	to master Impact of microbiological activity on waste stored in open ponds	
	Decision making process/ Treatment and categorisation of waste	Actions to facilitate decision making, Guidance on methodologies and strategies	in the choice of treatment process for ILW waste (efficiency, de-categorisation, volume reduction, compliance with WAC, etc.) for better, safer and cheaper results	Guidance
Q81. Radioactive waste conditioning	Choice for best matrix	Guidance	on choice of cement/ geopolymer/ vitrification for waste conditioning (LLW, ILW)	Development
		Development	to demonstrate long term behaviour of geopolymers	
		Action to better master	long-term performance, WAC and regulation - Need for demonstration	
		State of the art	in the development of molten salt treatment for minimization of waste	

	Solutions for Reconditioning of historical waste already conditioned	Benchmarking, Development and Guidance	on legacy/ historical waste management	Guidance
	Hydrogen production when conditioning reactive materials	Guidance	for conditioning of reactive materials including powdery ones	
		Development (R&D, software's, etc.)	to better master hydrogen evolution in matrices (software's, etc.)	Development
Q82. Radioactive waste packaging and logistics	Transportation of material for segmentation in the facility or on site	Share standard safety case	for transportation of material for segmentation in the facility or on site	Guidance
	Optimise packaging solution (from decom, transportation, storage to disposal)	Guidance and enhance harmonisation of practices	through coordination between Waste producers and WMO's to provide on best strategy for packaging: where? Type? Use of same containers for storage, transport and disposal, whatever storage extension?	
	Benefit from technological advances in monitoring	Actions to implement	new developments for waste monitoring in storage facilities to better survey waste behaviour during storage	Development
	Reusable material	Development and use of	shock absorbers for transportation packages made of reusable material instead of wood, etc.	Development
Q83. Characterisation and survey of containerised radioactive waste	Discussed in 3.4 'Characterisation'			

Q84. Material clearance (methodology and procedures)	Homogenisation of practices on clearance	Action to homogenise	practices for material clearance	Networking
	Enhance societal issues/dialogues	Actions related to societal issues/dialogues	for acceptance of reuse of material (see also §3.3)	Networking
	Enhance recycling of released materials	Actions to homogenise	good practices in recycling of released materials	Development
		Benchmarking	to create opportunities at international level for recycling inside nuclear sector	
		Benchmarking	at international level for cost with comparison of solutions (storage on sites, centralised depository, recycling in and out of nuclear sector	
		Actions to enhance	recycling of metal (in and out of nuclear sector)	
		Development	of processes and construction of metal melters to be able to process big pieces	
Q85. Material clearance (instrumentation and logistics)	Simplify and to improve reliability of measurement of waste prior to clearance	Development	of a characterisation platform to measure multi radionuclides directly for clearance (without need of nuclide vector)	Development
Q86. Management of hazardous and toxic materials	Management of Asbestos	State of the art and R&D	to improve management of contaminated Asbestos from decommissioning to disposal (See also Q70)	Development
	Need to improve management of PCB	State of the art and R&D	to improve management of PCBs (WACs etc.) (See also Q70)	

Q87. Conventional and cleared materials recycling (circular economy)	Public acceptance on recycled or clean waste from radioactive sites	Actions related to societal issues/dialogues	for acceptance of reuse of material	Networking
	Ability to recycle material cost effectively	Actions to homogenise	of good practices in recycling of released materials	
	Circular economy growth according to the market			

4. Conclusions/Highlights

The results of the gap analysis for each sub-thematic area in the 8 thematic area in terms of proposed actions that will serve as the basis for introducing the key research themes for the SRA and the roadmap are summarised as follows:

- In Safety and radiological protection, the proposed actions were oriented towards enhancement in international/national harmonisation; homogenisation of regulations; future coordination and collaborations; and regulatory guidance.

- In Project management, the proposed actions highlighted guidance on tools for cost management and digitisation; development of IT tools for project management; and enhance the use of BIM and virtual software.

- In Human resource management, the proposed actions encouraged coordination among EU, IAEA, and NEA to update existing documents for organisational rules and requirements; harmonisation towards knowledge bases for present and future end-users; enhance use of IT tools, training methods, and education of employees; and benchmarking on new methods and tools in KM for knowledge transfer and preservation.

- In Characterisation, the proposed actions suggested research and development for fast, cheap and straightforward methods for radionuclides (in-situ, ex-situ) measurement; development on innovation and technology for digital methods and automation; guidance on benchmarking, dissemination, and methodologies already implemented; and further developments towards knowledge management, training, and industrialisation.

- For Site preparatory activities, the identified needs were linked to waste management and addressed in that thematic area.

- For Dismantling, the proposed actions were oriented towards the development of technologies for detection, decontamination, and cutting of metals and concrete structures; research and development towards automation, digitisation, structured database, and innovative techniques; enhancement in the use of mobile systems and robotics for worker safety; guidance related to experience sharing, dismantling methodologies, and benchmarking; and standardisation of autonomous systems to uphold safety standards.

- In Environmental remediation and site release, the proposed actions highlighted the development of models, digital tools, multi-criteria analysis, and international guidance for remediation and site release; guidance on benchmarking for existing technologies and IT tools; and dissemination of experience exchange among stakeholders for coordination and harmonisation.

- For Radioactive waste management, the proposed actions suggested enhancements in the harmonisation of best practices and waste minimisation and optimisation opportunities; encouragement for the use of new technologies; development of simpler and cheaper processes for secondary waste handling and management; state of the art on IT tools and specific waste forms (liquid, Asbestos, etc.) management; harmonisation in standards for WAC's; Benchmarking and coordination for guidance. Moreover, some transversal actions related to societal issues and dialogues are also proposed.

As highlighted earlier, the extravagant list of proposed actions given in §3.1 to §3.8 for 71 sub-thematic areas were structured into 4 major types of actions, emphasising 'Networking', 'Dissemination', 'Developments', and 'Guidance' for global representation and can be seen in Figure 4-1.

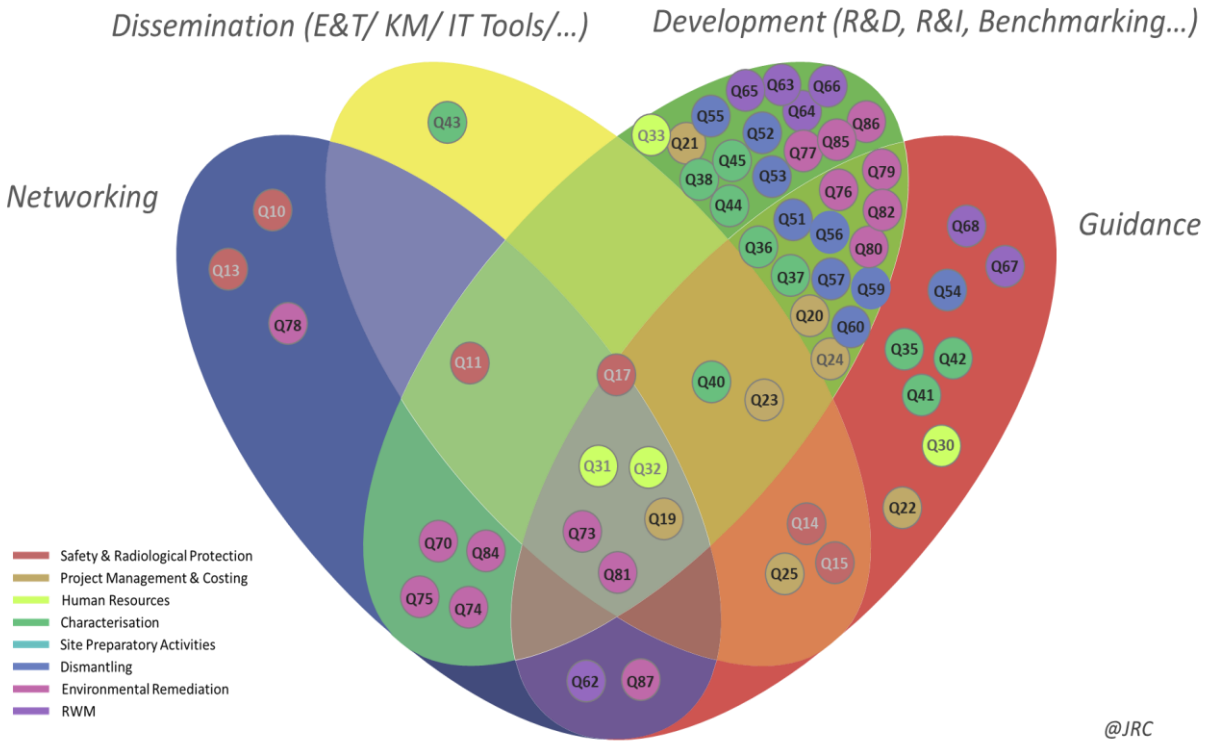

Figure 4-1 Overall distribution of the 71 sub-thematic areas in 4 main types of actions

The compiled actions through gap analysis, further grouped into 4 main types of actions will now be introduced as key research topics for future SRA and Roadmap for research in decommissioning. It will be briefly explained within the scope of WP4.