SHARE

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D4.1: Strategic Research Agenda

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Executive Summary

Decommissioning is a multi-disciplinary process, which includes activities such as physical and radiological characterisation of the site and its vicinity, and decontamination and dismantling of plant and building structures, eventually leading to the reuse of the site for some other purpose. Development and execution of a safe, efficient, and cost-effective decommissioning program requires input from many disciplines, and can significantly benefit from field experience and the availability of innovative technologies to optimize specific activities.

Considerable experience has been gained over the last decades in decommissioning various types of nuclear facilities, and the number of facilities entering decommissioning over the next 10-20 years will increase. Although the decommissioning activities have reached a certain level of maturity (high TRLs), further technological development work is required, particularly aiming at improving performances, safety and waste minimisation. Complex projects and challenges remain, amongst others for the D&D management of post-accident sites or reprocessing plants, to deal with the back-end of emerging reactor technologies, to tackle the risk aversion for new technology adoption, the lack of efficient knowledge sharing and harmonisation of regulations between countries, organisational issues, preserving scientific and technical competence, …

Decommissioning procedures today are precise, effective, and safe but often highly labour-intensive. While proven and safe techniques for dismantling are needed, new solutions to accelerate the process without sacrificing safety have to be developed by taking advantage of e.g. digital technologies. Both planning and execution of decommissioning can be facilitated by applications of 3D modelling and simulations, visualization, system automation and robotics, virtual reality, artificial intelligence, machine learning and other similar applications.

Recent reports[1,2] on innovation in decommissioning identified future suggested R&D areas and focus[3] on new aspects, trends and innovative technologies. SHARE continues the work on identifying research and innovation needs and crosscutting activities based on stakeholder involvement, with the scope to strengthen international networking and complementarity between national research programmes for decommissioning. This SRA identifies and prioritises activities needed to enhance the decommissioning field in various thematic areas.

For the non-technological topics of safety and radiological protection, project management, costing and human resources management in the first thematic area of the SRA, mainly crosscutting activities in the field of knowledge sharing, harmonisation of practices and education and training have been defined in comparison with technological RD&D topics. The needs that stand out most are education and recruiting of younger workforce, the development and dissemination of adequate digital tools to plan and follow-up decommissioning activities and the harmonisation of safety standards and waste criteria as enablers for collaboration.

[1] R&D and Innovation Needs for Decommissioning Nuclear Facilities, NEA No.7191, 2014
[2] SNETP Strategic Research and Innovation Agenda, 2021
[3] Advances and Innovations in Nuclear Decommissioning, M. Laraia, 2017

The thematic areas of characterisation and material and waste management overall have been identified by the stakeholders as most important and urgent, with activities for technology advances formulated in the field of measurement optimisation and waste treatment and conditioning techniques, together with crosscutting activities.

Innovative processes, technologies and methodologies for dismantling, decontamination and environmental remediation with a focus on waste minimisation and a need for further development in terms of efficiency improvement, mobility and/or automation are highlighted in the relevant thematic areas. Stakeholders emphasise also the need for sharing of best practices and development of guidance for certain aspects.

Ongoing initiatives and recent activities in all thematic areas demonstrate the continuous development and innovation, together with existing possibilities for exchange of information and lessons learnt. There are however few ways at present to go further and organise research and innovation multinational projects with co-financing by stakeholders facing common challenges. Public research has a potential role to play, in supporting future coordination of R&I efforts.

Deliverable content

Introduction

Decommissioning represents a crucial and highly complex stage of the nuclear cycle. There are still only few demonstrations of decommissioning programs which have been completed on an industrial scale. While decommissioning activities have achieved a certain level of maturity, further technological development work is required, particularly aimed at improving performances, safety and waste minimization. Individual countries are facing many challenges, including high development costs, difficulties in using innovative technologies or lack of resources. In this context, international coordination of activities between stakeholders is of the utmost importance.

The H2020 EU-funded SHARE project (StakeHolders- based Analysis of REsearch for Decommissioning) is a forerunner to the establishment of a framework for collaboration on research activities related to the decommissioning of nuclear facilities by providing an inclusive roadmap for decommissioning research built on a stakeholder consultation process. It is aimed at enabling cooperation in both technical and non-technical areas, in the EU and internationally, to improve jointly safety, reduce costs and minimize environmental impact.

Moving towards this goal, the SHARE Strategic Research Agenda (SRA) will help the EU and stakeholders to understand and assess the strategic areas to be recommended for financial support in the coming decades. The SHARE SRA considers research and innovation activities in the field of decommissioning that address these areas of improvement. It identifies the knowledge gaps and defines and prioritizes research topics to close those gaps by level of importance according to stakeholders' views. In addition to innovation and technological challenges, it also addresses policy, economics and social issues.

Perspectives from different stakeholders across the decommissioning value chain have been gathered from a consultation process by means of a survey, followed by subsequent interactive workshops on needs, available solutions and gaps. The resulting information forms the basis for this SRA. The overall approach and main findings leading towards the identification of potential research and innovative activities – in an broad sense – have been summarized in Annex.

The SRA scope is structured by six thematic areas, as illustrated in Figure 1. These thematic areas are also used in the roadmap. The thematic Area 1 considers all non-technical issues while thematic areas 2 to 6 focus mainly on technical issues.

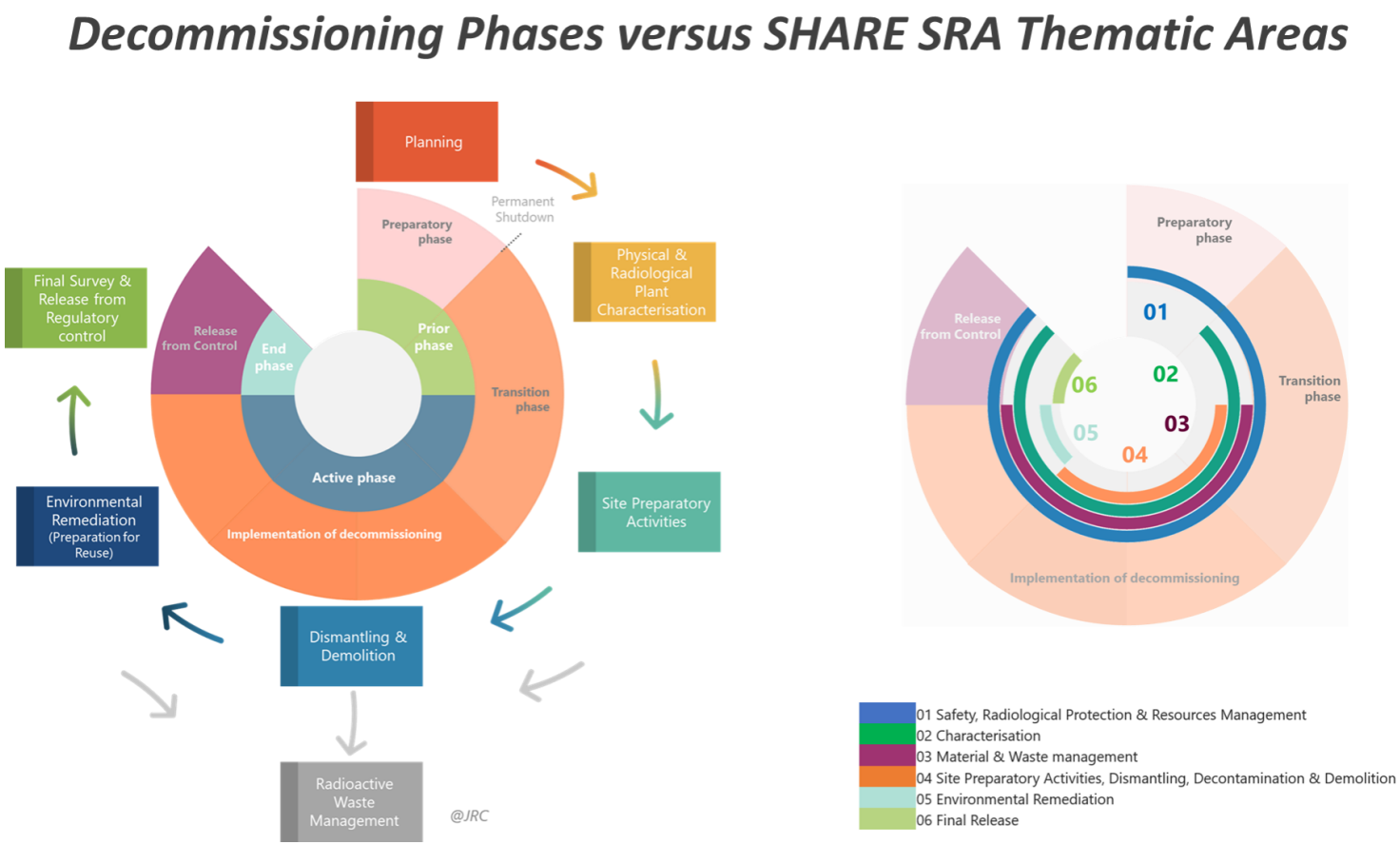

Figure 1: SHARE SRA Thematic Areas

The research needs highlighted by the SHARE survey were prioritized according to the survey-weighted analysis[4]. The following gap-analysis highlighted the gaps in technology, best practices and crosscutting activities[5].

The proposed actions to fill the identified gaps were categorised in four types of activities (Figure 2):

- implementation of research, development and demonstration (RD&D),
- knowledge sharing,
- education and training,
- harmonisation of practices.

The compiled actions, where further developments could lead to cheaper, faster and safer future decommissioning activities while improving safety, reduce costs and minimize environmental impact, are presented as main activities of common interest for six thematic areas of the SHARE SRA.

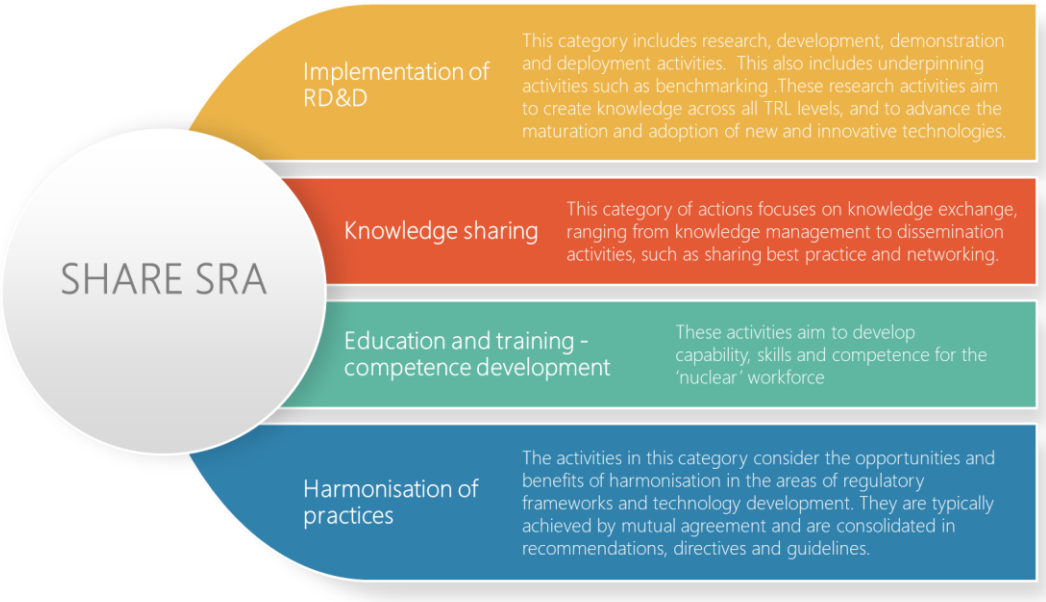

Figure 2: SHARE SRA Main Type of Actions

Within each thematic area, the SRA provides a short introduction, a list of RD&D priorities of common interest and a list of crosscutting activities to be addressed by the SHARE Roadmap. A summary of past and ongoing activities that address in part or in full, the activities and priorities identified for each thematic area is also presented.

[4] SHARE D2.5 Matrix and explanatory report from Task 2.3 https://share-h2020.eu/project-deliverables/
[5] SHARE D3.2: Technology assessment/ gap analysis report

Thematic Area 1: Safety, Radiological Protection and Resources Management

1.1 Safety and Radiological Protection

1.1.1 Introduction and Background

Nuclear safety and radiological protection of workers, the public and the environment, are important aspects of a decommissioning project which should be considered from the very beginning of work planning and licensing procedures up to site remediation and the final status survey. As such, there are obvious crosscutting aspects between TA01 and other thematic areas addressed in the SHARE SRA:

- Characterisation (TA02) of radiological conditions is required to assess workers exposures and plan optimisation of radiological protection.
- End state is mainly based on the definition of a dose constraint for the radiological protection of the public (TA06). This dose constraint has a large influence over waste management aspects (TA03).
- Clearance of radioactive materials is also based on radiological protection criteria, e.g. 10 uSv.y-1.

A number of international standards (EC Directive 2009/71, 2013/59 or 2014/87, for instance) exist and form the basis of EC Member States' national regulations with regards to safety and radiological aspects of decommissioning projects. Still, stakeholders (utilities, TSO, research organisations, etc.) identified areas for improvement (or gaps) related to those aspects. They are related to the following aspects:

- Practical guidance and experience sharing for occupational exposure management during decommissioning of nuclear facility;
- Harmonization of nuclear safety approaches for nuclear facility decommissioning projects;
- Methodology and procedures for the clearance of radioactive materials;
- Development of regulatory guidance for final site release.

A number of stakeholders also indicate that while an overall (holistic) and graded approach is required for occupational risk management (including radiological protection), there are too few examples of practical or regulatory guidance on these aspects, which remain quite challenging. Existing procedures, software or training programs (3D for occupational risks planning and training) do not adequately meet this goal so far. Improvement of occupational radiological protection and more globally protection of workers during decommissioning activities are expected, as well as benefits in terms of better allocation/distribution of protection resources.

1.1.2 Implementation of RD&D Activities

The RD&D Implementation activities of common interest, highlighted in the SHARE project in the field of safety and radiological protection are listed in the following section along with the relative priorities (ranking importance) identified in the SHARE weighted survey.

Thematic Area 1.1: Priority Activities					
Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q15. Methods and tools for nuclear safety	Activity (1): Development of digital tools for the preparation of safety report and the achievement of safety reviews for decommissioning project	Faster preparation and review of safety report	
MEDIUM		Q16/17. Radiological protection approaches and guidance for decommissioning	Activity (1): Development of tools for occupational risk management (planning and training)	Improvement of occupational risk management during decommissioning activities	

1.1.3 Crosscutting Activities

The related crosscutting activities identified in the field of safety and radiological protection are compiled in the following section. They are grouped into two main categories: knowledge sharing and harmonisation of practices.

Thematic Area 1.1: Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q11/12. Development of national regulatory guidance for decommissioning: preparatory activities + dismantling	Activity (1): Sharing of operational experiences	Effective communication and coordination between authorities Development of (interactive) digital support platforms	
HARMONISATION OF PRACTICES					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH	3	Q70. Management routes for materials including radioactive waste streams	Activity (1): Development of guidance and methodology for the definition of Waste Acceptance Criteria (WAC) for mixed waste	Ensure adequate disposal options for all waste streams arising for decommissioning of nuclear installations	
HIGH	3	Q84. Material clearance (methodology and procedures)	Activity (1): Define clearance values for liquids materials	Complete existing scheme for the clearance of radioactive materials	
	3		Activity (2): Complete existing set of clearance values in international standards	Easier management of materials arising from the decommissioning of research facilities and other nuclear facilities	
			Activity (3): Guidance on practical translation of regulation (calculation validation, averaging rules)	Shorter (administrative) routes for clearance	

Ranking Importance	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH	6	Q14. Development of national regulatory guidance for decommissioning: final site release	Activity (1): Guidance on methodology for the definition of the end state considering all pollutants	Harmonization of national approaches and support to Member States without nuclear industry	
	6		Activity (2): Guidance for stakeholders' engagement process for the definition of the end state	Increase acceptance and confidence in decommissioning projects	
MEDIUM	4	Q10. Harmonization of safety standards and safety approaches for decommissioning	Activity (1): Standardisation of safety approach through harmonization of national regulatory frameworks and requirements	Favour graded and flexible approach for safety as required for decommissioning activities Distribute the application of digital (support) tools and technologies for simulation and automation	
MEDIUM		Q11/12. Development of national regulatory guidance for decommissioning: preparatory activities + dismantling	Activity (1): Enhance international harmonisation	Facilitate decommissioning licensing and shortening transition from operation to decommissioning Integrate decommissioning and environmental remediation with waste management	
MEDIUM		Q16/17. Radiological protection approaches and guidance for decommissioning	Activity (1): Development of guidance to improve occupational radiological protection and more globally to improve the protection of workers during decommissioning activities	Better allocation of protection resources	

1.1.4 Ongoing Initiatives and Recent Activities

Radiological protection will benefit from improvement in characterisation of facilities and areas and thus from H2020 projects such as INSIDER[6] (even if this project is primarily devoted to waste management) or CLEANDEM[7]. These projects related to TA02 are described in more details in the follow-up of the SRA.

The IAEA recently published TecDoc 'Occupational Radiation Protection during the Decommissioning of Nuclear Installations, Main Aspects of Management, Planning and Conduct' (IAEA-TECDOC-1954, 2021)[8] which addresses the question of radiological protection during decommissioning of nuclear facilities, outlining among others things the need for an holistic approach for risk management.

The IAEA as well as the NEA provide support for the sharing of experiences in the field of decommissioning of nuclear facilities including safety and radiological protection issues, such as the NEA CDLM HDCS Expert Group[9] or the ongoing IAEA COMDEC project[10] which aims at reviewing experience in the field of defining the desired final status of decommissioning. The COMDEC project aims at demonstrating compliance with end-state criteria and defining and implementing any necessary measures and controls after the end of decommissioning. It is expected to contribute to an update of IAEA Safety Guide (No. WS-G-5.1) on "Release of Sites from Regulatory Control on Termination of Practices"[11].

The new NEA Expert Group on Comparison and Understanding of Dose Prognosis (EGDP) aims to facilitate collaboration in improving coordination through a common understanding of the outputs of dose projections codes, which influence the decisions on protective actions.

[6] INSIDER: Improved Nuclear Site characterization for waste minimization in DD operations under constrained EnviRonment
https://cordis.europa.eu/project/id/755554

[7] CLEANDEM: Cyber physicaL Equipment for unmAnned Nuclear Decommissioning Measurements
https://cordis.europa.eu/project/id/945335

[8] https://www.iaea.org/publications/14858/occupational-radiation-protection-during-the-decommissioning-of-nuclear-installations

[9] CDLM HDCS Expert Group: Committee on Decommissioning of Nuclear Installations and Legacy Management Expert Group on a Holistic Process for Decision Making on Decommissioning and Management of Complex Sites
https://www.oecd-nea.org/jcms/pl_62828/decommissioning-complex-and-legacy-sites

[10] COMDEC Project : International Project on Completion of Decommissioning

[11] https://www.iaea.org/publications/7433/release-of-sites-from-regulatory-control-on-termination-of-practices

1.2 Project Management and Costing

1.2.1 Introduction and Background

Project Management and Costing is one of the central non-technical areas in the decommissioning of nuclear facilities. The size and complexity of such projects that often include many organisations and are subject to heavy regulations, require careful planning and methodical execution.

Typically, in the **planning phase**, different decommissioning scenarios are developed and compared. The scenario construction leads to a complex system of tasks, defined by a work breakdown structure, waste management routes, overhead costs and R&D for technology development including the decommissioning operator and different contracting parties. Scenario choice is based on the typical project management categories *cost, duration and quality* whereas the latter category includes worker safety and radiological protection and the desired radiological end-state. In terms of cost and duration, today, a minimization is desirable. An evaluation of this type requires a competent team of project managers and an efficient system of knowledge management to collect information about the operational history. A high degree of expertise is desirable to correctly assess uncertainties and risks and their effects. In the current age of digitalisation, all of this also means the effective use of project management software and data collection tools, for example, in a BIM model.

In the **decommissioning phase**, project execution relies on good communication of the current expenses and the status of the facility. This way, project managers can effectively coordinate the interventions of different contracting parties on the site and the timely removal and treatment of radioactive waste. In the case of anticipated or unforeseen problems, good communication among the parties can help mitigate project risks and coordinate the planning adjustments. Lastly, nuclear projects are often polarizing in public communication. Engaging with all stakeholders[12] and involving them in decision making processes is therefore essential throughout the life cycle of nuclear facilities.

Currently, finding standards for piloting decommissioning projects is difficult. No facility resembles another and, therefore, transposing activities between projects is delicate. However, the International Structure for Decommissioining (ISDC) codeveloped by the OECD-NEA, the IAEA and the EC may serve as fundamental work breakdown structure. Other industries with large scale projects created benchmarking organisations or structures that allow for optimisation that, ultimately benefits the whole sector. In the nuclear field, such initiatives remain rare.

The DACCORD[13] project confirmed the role of decommissioning project management to be one of the most important factors to control decommissioning costs either directly by good project management, safety assessments, and a waste management plan or indirectly by short decommissioning project duration that limits running costs associated to site infrastructure and operation.

[12] IAEA Nuclear Energy Series NG-G-5.1 on Stakeholder Engagement in Nuclear Programmes, 2021

[13] DACCORD: Collaborative IAEA Project on Data Analysis and Collection for Costing of Research Reactor Decommissioning which supports Member States in preparing preliminary cost estimates for the decommissioning of research reactors

1.2.2 Implementation of RD&D Activities

The RD&D Implementation activities of common interest, highlighted in the SHARE project in the field of project management and costing are listed in the following section with the relative priorities (ranking importance) identified in the SHARE weighted survey.

Thematic Area 1.2: Priority Activities Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q25. Methodologies and guidance for cost estimation	Activity (1): Improve and broaden guidance on cost estimation methodology, dealing with all costs (waste management, engineering, risks etc.) and all types of nuclear facilities to make benchmarking easier	Improve the (application of the) benchmarking activities for costing issues	
			Activity (2): Establish working groups for cost estimation for various facility types		
MEDIUM		Q21. Tools for data collection in the field (e.g. work monitoring)	Activity (1): Improvement of communication between information systems (data collection tools with other project management software)	Improvement of data collection technology in terms of automatisation, communication and interconnectivity Better planning and follow-up	MICADO
			Activity (2): Enhance the use of IT tools to monitor logistics flow, new technologies for characterisation and inventories and IT tracking systems for waste management	Enhance the use of data collection technologies through demonstration & deployment	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q22. Digital transformation in decommissioning	Activity (1): Development of electronic data management	Improvement of data and information management for the digital transformation in decommissioning	PLEIADES MICADO
			Activity (2): Enhance the use of modern data collection techniques through demonstration & deployment	More qualitative and interactive/ interconnective data acquisition	
			Activity (3): Enhance the use of VR, 3D modelling and digitisation through demonstration & deployment	Advance TRL and application	
MEDIUM		Q19. Methodologies and software tools for comparison of alternative decommissioning strategies and components	Activity (1): Development for long term data storage	Improvement of interoperability and efficient data sharing	PLEIADES
			Activity (2): Development of available tools for cost estimation for application of risk and uncertainty analysis (ISDC, different by facility type)	Improvement of tools for calculation sensitivity and uncertainty analysis Better addressing of risks and uncertainties	NuBaFa
			Activity (3): Developments of the methodology to define unknowns and the associated uncertainty		

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
LOW		Q20. Methodologies and software tools for project management and performance monitoring	Activity (1): Development of project management tools that take decommissioning specificities into account	Retrofitting of existing tools with decommissioning specificities or development of new software	PLEIADES MICADO
			Activity (2): Enhance the use of BIM tools among decommissioning projects	Asset data and information management	PLEIADES
			Activity (3): Development to enhance interoperability between software tools used in decommissioning from strategy and scenario analysis to monitoring on site	Facilitate collaboration on the project management level	
			Activity (4): Developments for collaborative features in software tools		
LOW		Q23. Supply chain management	Activity (1): Developments on risk analysis and risk sharing practices during contracting	Improvement of the supply chain management	
LOW		Q27. Development of mechanisms for cost benchmarking.	Activity (1): Improvement in approaches and data sharing for cost benchmarking	Improving cost efficiency by comparing estimates with actual costs	
			Activity (2): Further development of the cost benchmark methodology in coordination with the NEA EGCDL Expert Group		

1.2.3 Crosscutting Activities

The crosscutting activities related to project management and costing are compiled in the following section. They are grouped into three main categories: knowledge sharing, education & training / competence development and harmonisation of practices.

Thematic Area 1.2: Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q19. Methodologies and software tools for comparison of alternative decommissioning strategies	Activity (1): Consultation with experts in- and outside the nuclear industry for scenario evaluation and tools selections	Improve decommissioning efficiency	PLEIADES
			Activity (2): Coordination of (local) activities with IAEA, OECD-NEA, other EU projects etc.	Overview of the developments for peer review and dissemination	
MEDIUM		Q24. Methods and tools for communication	Activity (1): Sharing of best practices for education	Improve public attitude towards nuclear Engage youth to decommissioning	ANNETTE ENEN+
			Activity (2): Development and use of (modern) communication tools to explain what decommissioning is (site visits, etc.)	Improvement of communication with local community, improvement of communication tools and building a general communication plan	

Ranking Importance	TA Link	Sub thematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q25. Methodologies and guidance for cost estimation	Activity (1): Guidance for determining the significant cost drivers per project	Identify cost drivers	
			Activity (2): Action related to coordination on public case studies of costing (budget vs realised)	Provide public data for cost estimation	
LOW		Q20. Methodologies and software tools for project management and performance monitoring	Activity (1): Guidance on best tools for project management dedicated to decommissioning	Enhance the use of performant project management tools	
EDUCATION& TRAINING / COMPETENCE DEVELOPMENT					
Ranking Importance	**TA Link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
LOW		Q23. Supply chain management	Activity (1) Enhance the use of, for example, immersive rooms by contractors to simulate dismantling scenarios and to train for activities	Improve training facilities Safety improvement through better preparation	PLEIADES

HARMONISATION OF PRACTICES					
Ranking Importance	**TA Link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q19. Methodologies and software tools for comparison of alternative decommissioning strategies	Activity (1): Standardisation	Enhance interoperability of IT tools	PLEIADES
			Activity (2): Guidance to address uncertainty during scenario analysis	Improve strategic oversight and quality assurance	
MEDIUM		Q25. Methodologies and guidance for cost estimation	Activity (1): Dissemination of ISDC guidelines in coordination with OECD-NEA and IAEA	Harmonisation of work breakdown structures for cost estimation	
MEDIUM		Q21. Tools for data collection in the field (e.g. work monitoring)	Activity (1): Guidance on system thinking (holistic) approach to digitalisation	Provoke synergistic effects by working on interfaces between different activities and groups	
			Activity (2): Enhance the use of digital methods for decommissioning through guidance and standardisation	Guidance on the strategic approach towards digitalisation	
MEDIUM		Q24. Methods and tools for communication	Activity (1): Guidance for stakeholders in addressing the public	Include a societal perspective to decommissioning projects	
LOW		Q23. Supply chain management	Activity (1): Standardisation of role definitions in project management	International standardisation and knowledge management for improved collaboration	
			Activity (2) Enhance the use of standardised practices in the field of waste management		

1.2.4 Ongoing Initiatives and Recent Activities

ISDC: The reference for cost calculation for decommissioning projects is the International Structure for Decommissioning Costing (ISDC) developed in 2012 by the OECD-NEA, the IAEA, and the European Commission. The common structure seeks to facilitate the planning and cost estimation of decommissioning projects for Owners/Licensees. The original report gives an overview of classical cost estimating techniques and the phases of a decommissioning project before detailing a hierarchical structure that aims at breaking down complex projects into individual activities that can be quantified and evaluated for difficulty.

IAEA-DACCORD: Using the ISDC, DACCORD analysed the costing details of 20 research reactors to identify the most important cost factors. Moreover, they performed statistical analysis in order to take uncertainty into account. Cost estimation was performed using the CERREX-D2 software.

EGCDL: The OECD-NEA animates the Committee on Decommissioning of Nuclear Installations and Legacy Management (CDLM) consisting of members from the NEA groups and the EC in close collaboration with the IAEA. Within this committee the Expert Group on Costing (EGCDL) works, among other things, on cost benchmarking. In 2019, they presented a report[14] on the barriers and enablers for the institution of a cost benchmarking organisation.

NuBaFA: The permanent Group of Experts created in April 2021 by the European Commission is charged with coordinating the views of member states on topics such as the assessment of uncertainties in cost estimates for decommissioning, the assessment of national programmes for radioactive waste management, the assessment of the risk profile of decommissioning funds, and the cost benefit of mutualisation of practices.

PLEIADES: PLEIADES is an EU-funded project that aims at developing a software platform based on a modular approach that will be tested in three case studies. A common standardized data structure will allow the integration of different modules into a single BIM based software ecosystem. The Platform should be able to provide a comprehensive project management support with focus on dose, waste and scenario safety assessments, including in real-time.

LiveDecom is a Norwegian Industrial Innovation project with both Norwegian and international partners. It started one year earlier than PLEIADES and aimed at prototyping a BIM based modular nuclear decommissioning support ecosystem connectable with application of mobile robots equipped with 3D scanners, as well as radiological and other sensors.

MICADO: The EU-funded project aims at, among other things, developing a Digital Waste Platform that should allow the easy tracking of waste and its characteristics.

INNO4GRAPH: The EU-funded project aimed at developing a tools and methods for graphite reactor dismantling before the selection of the operation (scenario choice) and during dismantling.

ENEN + & ELINDER: Initiatives that support Euratom's objective of maintaining and enhancing the EU's nuclear competences. Their objective is to attract new talents to careers in the nuclear sector.

[14] Cost Benchmarking for NPP Decommissioning, NEA No.7460

1.3 Human Resources Management

1.3.1 Introduction and Background

Besides a variety of technical aspects, human resource considerations are equally paramount in the decommissioning of nuclear facilities. This involves the training and qualification of personnel, change management, human performance improvement and knowledge preservation policies and practices.

The transition from an operating nuclear facility to the decommissioning phase is critical in the life cycle of every facility. A number of organisational and technical modifications are needed in order for the facility to meet new objectives and requirements, and a certain number of activities must be initiated to support the transition and preparation for the dismantling of the facility. The decommissioning of nuclear facilities itself includes several phases, which implies a variety of business opportunities for a number of actors. Decommissioning a large and/or complex nuclear facility, or indeed several of them at the same time, fosters an ecosystem of very large environmental services contractors as well as smaller specialist companies. Project/change management aspects, commercial and contractual management, and innovation management learnings are areas where experiences can be transferred between nuclear and non-nuclear activities.

One of the cornerstones of the success of nuclear facility decommissioning is the adequate competence of personnel involved in decommissioning activities. Systematic competence development in the long run is therefore needed to guarantee the necessary wide range of skills and capabilities over the full duration of the project. The demographic challenge of retirements within the industry needs to be addressed through focused/tailored training programmes and mobility support to attract the younger workforce.

The adoption of advanced and emerging technologies for training purposes providing digital solutions and simulation/visualisation capabilities using virtual reality can help both in organising decommissioning training more (cost-)effective and in attracting a new generation of talent.

Nuclear decommissioning is a complex process involving a range of stakeholders and creating an array of paper, digital and other records that need to be preserved to support day-to-day operations and beyond. Within nuclear facility institutions or organisations records can support training, long-term strategy evaluation, monitoring and development, transparency and accountability, but are also vital for planning decommissioning. Some pressing challenges being faced today: processing the ‘huge backlog’ of paper and digital records, ensuring the industry’s operational needs continue to be met and working to create an archive for posterity.

Existing international standards set out guiding principles for organisations and acknowledge that there is no ‘one size fits all’ solution to the effective management of knowledge. Organisations have to consider what are the critical knowledge assets, plan a strategy to meet business objectives, decide what knowledge management platform and tools to use on a systematic approach and consider how to evaluate the effectiveness of the processes implemented.

International initiatives, workshops, publications and reports (IAEA, NEA) on training and (other) human resource considerations like transition strategies, record keeping and knowledge management are well established, but this does not prevent the stakeholders considering some topics to be in need of further development. The focus hereby lays more on the further development or application of existing methods and tools, plus the sharing of existing knowledge and best practices.

1.3.2 Implementation of RD&D activities

The RD&D Implementation activities of common interest, highlighted in the SHARE project in the field of human resources management are listed in the following section with the relative priorities (ranking importance) identified in the SHARE weighted survey. Focus in this thematic area is clearly on the crosscutting activities.

Thematic Area 1.3: Priority Activities Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q32. General education for decommissioning	Activity (1): Benchmark best practices for local and international knowledge transfer (and retention)	Identify opportunities for tailored training, cross-sectorial learning, distance learning, digital information management (complementing traditional methods) Qualitative and up-to-date education and training (E&T) programmes to ensure (sufficient and) skilled staff are available for the sector	ELINDER ANNETTE

1.3.3 Crosscutting Activities

Thematic Area 1.3: Priority Crosscutting Activities KNOWLEDGE SHARING					
Ranking Importance	**TA link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q32. General education for decommissioning	Activity (1): Enhance international mobility (provide internships & certifications etc)	Stimulate job attractiveness plus information exchange	ELINDER ENEN+
HIGH		Q31. Methods and software tools for knowledge management (KM)	Activity (1): Benchmark and dissemination on new methods and tools in KM for knowledge capture and preservation	Better application of existing methodologies Improvement in tools for KM	
			Activity (2): Actions to coordinate KM efforts internationally (from a data & software interoperability perspective)		
			Activity (3) Establish protocols for knowledge collection during operational phase useful during decommissioning		
LOW		Q30. Organisation models	Activity (1): Coordination between EU, IAEA and NEA to disseminate information on organisational transformation from operations towards decommissioning (e.g. in the case of transfer of license or after prolonged period of deferred dismantling etc.)	Best practices taking site/project parameters into account Evolution towards more optimised/rigid organisations will positively impact planning, cost	

Ranking Importance	TA link	Sub thematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
LOW		Q30. Organisation models	Activity (2): Coordination between EU, IAEA and NEA to disseminate information on intra-organisational best practices to achieve a more efficient organisation (multi-functional decommissioning team-based structure, alternatives to department structure etc.)	Best practices taking site/project parameters into account Evolution towards more optimised/rigid organisations will positively impact planning, cost	
EDUCATION & TRAINING / COMPETENCE DEVELOPMENT					
HIGH		Q32. General education for decommissioning	Activity (1): Enhance cooperation related to E&T between industry, universities and research organisations; information should be integrated in the overall KM	Training programmes with focus on decommissioning Evaluate options of distance and cross-sectorial learning	ELINDER
			Activity (2): 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.)	Application of new technologies Improve efficiency and safety	
HIGH		Q31. Methods and software tools for knowledge management (KM)	Activity (1): Actions related to E&T to secure, attract and motivate young workforce in D&D	Fulfil urgency to train new generation	ENEN+

Ranking Importance	TA link	Sub thematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q33. Methodologies and tools for task specific training	Activity (1): Identify priorities in emerging training needs & requirements in decommissioning	Integration of digital tools complementing traditional methods	
			Activity (2): Promote use of immersive training methods and simulation tools (through recognition, standards, certification etc)	More realistic, qualitative, interactive and cost-effective training methodologies (complementing traditional methods)	
LOW		Q30. Organisation models	Activity (1): Actions to promote E&T among employees, sharing between countries & organisations; cooperation between actors involved, industrial partners etc (from a training plus organisational R&D need perspective)	Training programmes with focus on decommissioning Evaluate options of distance and cross-sectorial learning	ELINDER
HARMONISATION OF PRACTICES					
HIGH		Q32. General education for decommissioning	Activity (1): Harmonise levels of education required for decommissioning (certifications for specific skills sets etc.)	Evolution towards more tailored education and skill development	ELINDER EHRO-N
LOW		Q30. Organisation models	Activity (1): Establish common rules and requirements to provide access to international decommissioning markets	Increase competitiveness and market fragmentation Optimisation in contracting strategy	

Ranking Importance	TA link	Sub thematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
LOW		Q30. Organisation models	Activity (2): Harmonise knowledge bases for future end users in decommissioning operations (through KM formats, data interoperability, information hierarchy, optimisation of knowledge transfer processes, integration of security standards in the methods and software, etc.)	Better competence preservation	

1.3.4 Ongoing Initiatives and Recent Activities

A study on needs, opportunities and challenges in Europe for **education and training** in decommissioning revealed that already a wide spectrum of education and training programmes exists. A significant step for improvement was identified in combining the efforts of universities and institutes for the creation of a joint modular training programme in decommissioning that could be practiced at different places, with well-defined training outcomes.

The European Learning Initiatives for Nuclear Decommissioning and Environmental Remediation (ELINDER) is a training programme in nuclear decommissioning. ELINDER is organised in a set of complementary training courses, providing a common qualification. ELINDER is coordinated by the European Commission Joint Research Centre (JRC) in collaboration with several partners including European universities and institutes specialised in the nuclear sector. The courses, including visits and practical studies, are provided by each partner in different European countries.

The European Human Resources Observatory for the Nuclear Sector (EHRO-N) was established to analyse the situation of the human resources of the nuclear energy sector in Europe. The Nuclear Job Taxonomy (NJT) is a classification of jobs in NPPs. It sets the focus in the requirements for each position defined in terms of knowledge, skills and competences.

The ANNETTE project within the ENEN on Advanced Networking for Nuclear Education and Training and Transfer of Expertise has been finalised end 2019. It aimed at tackling the challenges in preparing the European workforce in the different nuclear areas with special attention to continuous professional development, life-long learning and cross border mobility.

Cognisant of the particular demand for **information, data and knowledge management** in radioactive waste management, decommissioning and legacy management, the NEA has established several activities to address this area of work. The creation of the Working Party on Information, Data and Knowledge Management (WP-IDKM) and the publication of the IDKM Roadmap in 2019 has resulted in international collaboration within this working party framework to address challenges related to archiving and preserving information, data and knowledge for a timescale across (many) generations.

IAEA periodically organises Technical Meetings on topics related to Human Resources Management:

- IAEA Technical Meeting on Advancing Human Resource Development and Competence Building for Decommissioning (Dec 2021)
- IAEA Technical Meeting on Advancing Collaboration on Competence Building and Knowledge Management for Decommissioning (Dec 2020)
- IAEA Technical Meeting on Human Resource Development for Decommissioning (Jul 2019)

A recent update[15] on the lessons learned and best practices relating to the decommissioning of nuclear facilities is published by the IAEA to provide guidance on human resource and training considerations. Numerous knowledge sharing and remote learning initiatives are available by IAEA Supported Tools, such as NUCLEUS and CLP4NET.

The NEA Nuclear Education, Skills and Technology (NEST) Framework helps to address important gaps in nuclear skills capacity building, knowledge transfer and technical innovation in an international context. The goal of NEST is to:

- energise advanced students to pursue careers in the nuclear field by proposing a multinational framework among interested countries to maintain and build skills capacities;
- establish international links between universities, academia, research institutes and industry;
- attract scientists and technologists from other disciplines to examine nuclear technology issues and involve such actors in the resolution of real-world problems.

[15] Training and Human Resource Considerations for Nuclear Facility Decommissioning, NG-T-2.3 (Rev.1), IAEA, 2021

Thematic Area 2: Characterisation

2.1 Introduction and Background

Characterisation is the basis for radiation protection, identification of contamination, assessment of potential risks, cost estimation, planning and implementation of decommissioning of nuclear facilities. Characterisation is relevant in all phases of the life cycle of a nuclear installation with different levels of detail and with differing objectives. The following characterisation phases can be identified: characterisation prior to operation; characterisation during operation; characterisation during the transition phase; characterisation during decommissioning, including decontamination; and characterisation for environmental remediation as well as to support the end-state study for site release.

The most extensive characterisation campaigns are carried out during the transition phase to prepare for the implementation of decommissioning activities as well as 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 and treatment of radioactive materials. The final status survey on the site have to consider the possibility of subsurface contamination, which may lead to radionuclide transfer into ground water and surface water bodies.

The main feedback collected during the gap analysis workshop, in terms of needs and opportunities, in the field of characterisation can be summarised as:

- Fast, cheap and straightforward methods for difficult to measure (DTM) radionuclides (in-situ, ex-situ);
- Demonstration and industrialisation of sensors, drones, integrated and automated systems;
- Easy and straightforward indoor positioning systems combined with data management;
- Machine learning and AI (data management, digital archive, statistical sampling, modelling);
- Guidance, knowledge management, exchange of information and education & training.

2.2 Implementation of RD&D activities

The RD&D Implementation activities of common interest, highlighted in the SHARE project in the field of characterisation are listed in the following section with the relative priorities identified in the SHARE weighted survey.

Thematic Area 2: Priority Activities Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH	**03**	Q53. In situ radioactive waste characterisation and segregation	Activity (1): Development of remote and automatic systems for in situ characterisation of alpha radiation	Improvement on existing technologies	METRODECOMII CLEANDEM
			Activity (2): Development of integrated systems for simultaneous radiological and chemical characterisation	Towards innovation of autonomous systems (Automation)	
			Activity (3): Development of systems for the accurate characterisation and visualisation of waste packages	Towards innovation of integrated systems	
			Activity (4): Methodologies and technologies for characterisation of mixed waste with concrete	Optimisation of waste segregation Material recycling and reuse	
HIGH	**03** **04**	Q38. Characterisation of activated components and areas (Concrete)	Activity (1): Development of methodologies and technologies for DTM in situ, in lab and automation	Fast, cheap and straightforward methods for difficult to measure (DTM) radionuclides reducing time and characterisation cost	METRODECOMII, MICADO, CLEANDEM

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH	03 04	Q38. Characterisation of activated components and areas (Concrete)	Activity (2): Development of methods for characterising concrete at depth/ 3D Hot spots	Non-invasive real-time sensing technologies to characterise the concentration of radionuclides, including DTM, as a function of depth, within concrete Eliminate difficulties associated with core sampling and subsequent analysis reducing time and characterisation cost	METRODECOMII, MICADO, CLEANDEM
			Activity (3): Benchmarking, development and demonstration of indoor positioning systems	Comparison, optimisation and enhancement of use	
HIGH	04,05	Q40.Technologies for hard to access areas (high walls, embedded components, harsh environment…)	Activity (1): Towards the industrialisation of robotics, including drones and sensors	To enhance the use of robotics, drones and sensors (current lack of attention directed towards their establishment in the nuclear industry) Developing technologies will require suitable infrastructure to scale up to meet market opportunities	
HIGH	04	Q37. Characterisation of activated components and areas (Metal)	Activity (1): Development of technologies to map activity on large metallic components	Automation of the combined techniques	MICADO
			Activity (2): Development of methodologies and technologies for DTM including automation	Methodologies and technologies for DTM including automation	METRODECOMII
			Activity (3): Benchmark methodologies for in situ characterisation in high dose environments	Comparison and validation of characterisation methodologies in hostile environment	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH	05 06	Q62. Clearance of surfaces and structures (interiors and exteriors)	Activity (1) Development of autonomous radiological characterization techniques of structures and land areas for final status surveys and release	Automated characterisation systems for clearance	
HIGH	05	Q63.Characterisation methods and technologies to identify subsurface contamination	Activity (1): Improvements of characterisation techniques for underground contamination at low and very low levels	Reliable, adequate characterisation methods to identify subsurface radionuclide contamination Assess long-term transport via environment	
			Activity (2): On-line characterisation during remediation and clean-up focusing on automation	Automation	
MEDIUM	03	Q83. Characterization and survey of containerized radioactive waste	Activity (1): Technologies using mobile systems to characterise containerised RW	Mobile system for in situ characterisation. Legacy wastes	CHANCE
			Activity (2): Technologies and methodologies for characterisation of unconventional legacy waste. Integrated systems	Integrated systems for legacy waste characterisation	CHANCE
MEDIUM	04	Q45. Alpha and beta non-destructive measurements	Activity (1): Technologies for fast (accurate) alpha and beta non-destructive measurements	Fast, cheap, and straightforward methods for in situ DTM determination	METRODECOMII TRANSAT
MEDIUM	04 05	Q44. Sample analysis technologies	Activity (1): The development of rapid, cheap, and straightforward methods for sample analysis including automated methods. Benchmarking	Improvement of existing technologies and benchmarking	METRODECOMII

2.3 Crosscutting Activities

The related crosscutting activities identified in the field of characterisation, included in the SRA TA02 Characterisation, are compiled in the following section. They are grouped into three main categories: knowledge sharing, education & training / competence development and harmonisation of practices.

Thematic Area 2: Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q36. Inventory assessment (Radiological and non-radiological	Activity (1): Enhance and improve the use of models for radiological and non-radiological inventory assessment Activity (2): Guidance on methodology and techniques for the radiological inventory.	Implementation of digital technologies to improve key tasks in the decommissioning BIM and Digital twins to add value and accelerate the decommissioning programmes	PLEIADES CLEANDEM
HIGH	05 06	Q63. Characterisation methods and technologies to identify subsurface contamination	Activity (1): Exchange and dissemination of best practices	Guidance on best practices for on-line characterisation during remediation and clean-up.	
MEDIUM	06	Q67. Methodologies and techniques for final release survey of the Site	Activity (1): Dissemination of best practices	Guidance on methodologies to characterise the underground remaining structures	
MEDIUM		Q35. Methodology for historical site assessment	Activity (1): Historical information data management as form of digital archive as well as georeferenced information	Accurate site model. Implementation of digital technologies (BIM, Digital twins)	PLEIADES CLEANDEM
MEDIUM	04 05	Q42. Standards for statistical sampling	Activity (1): Guidance for statistical sampling methodologies	Development of an international approach and/or a standard for statistical sampling considering representativeness, grid density, and defining an acceptable level of uncertainty	INSIDER

Ranking Importance	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM	04	Q41. Development of modelling and simulation software for characterisation of irradiated components	Activity (1) Models validation and simplification	Guidance on methodology, benchmarking and dissemination on models	
LOW	04	Q55. Dismantling of surface-contaminated piping and small components	Activity (1) Exchange of experiences Dissemination of best practices	Guidance on methodology for the characterisation of residual solvents in piping and vessels	
EDUCATION& TRAINING / COMPETENCE DEVELOPMENT					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH	04	Q40.Technologies for hard to access areas (high walls, embedded components, harsh environment	Activity (1) Robotic platform deployments needs upskilling of the workforce	Educational and training programmes to ensure sufficient and skilled staff are available for the sector	ENEN + ELINDER
LOW	04 05 06	Q43. Geostatistical software applications	Activity (1): Upskilling of the workforce		
HARMONISATION OF PRACTICES					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH	04 05 06	Q40.Technologies for hard to access areas (high walls, embedded components, harsh environment	Activity (1) Evaluate the regulatory implications of using advanced manufacturing technologies including robotics, automated site mapping, additive manufacturing and digital twin technology	Alignment and harmonisation based on EU standards enabling an efficient comparison of the efficiency, the suitability and the limits of available techniques being used in similar conditions	
HIGH	04 05	Q62. Clearance of surfaces and structures (interiors and exteriors)	Activity (1): Identification of Member States' regulatory differences regarding clearance criteria	Identify opportunities to improve the exchange of experiences. Pros & cons harmonisation	

2.4 Ongoing Initiatives and Recent Activities

Ongoing or recently concluded EU projects are addressing selected activities related to the needs highlighted in some of the sub thematic areas compiled in the SRA TA02 Characterisation.

The EURAMET EMPIR project METRODECOMII[16] main outcomes are:

- the development and implementation of a novel automatic measurement system to check whether waste packages are safe for disposal or must be treated as radioactive waste;
- the development of in situ methods for the rapid radionuclide characterisation of the different types of materials present on decommissioning sites. This includes the development of novel measurement techniques that improve the mapping of contamination inside nuclear facilities and the determination of statistically valid and effective sampling methods. METRODECOMII covers in situ alpha detection;
- the development and implementation of rapid methods for destructive analysis of the radioactivity content of materials on a nuclear site. This includes automated digestion methods, automated radiochemistry system for 90Sr determination and semi-automated microfluidic devices designed for separations that are more complex and simultaneous determination of alpha and beta radionuclides.

The MICADO H2020 project[17] is covering non-destructive characterization of nuclear waste and the implementation of a digitization process aiming at providing a referenced standard for facilitating and harmonizing the methodology used for the in-field Waste Management and Dismantling & Decommissioning operations.

The development of technologies for rapid and non-destructive measurements of alpha and beta emitters (e.g. 3H, 90Sr, 14C, 36Cl, 63Ni) of the different types of materials present on decommissioning sites has been identified as a need. The outcome of the Euratom H2020 TRANSAT project could cover some aspects related to the development and use of techniques such as autoradiography, ion beam technology and LIBS and the state of the art methodologies for tritium determination.

The main objective of the CHANCE H2020[18] project is to establish a comprehensive understanding of current characterization methods and quality control schemes for conditioned radioactive waste in Europe. These techniques included were the calorimetry as an innovative non-destructive technique to reduce uncertainties on the inventory of radionuclides; the Muon Tomography to address the specific issue of non-destructive control of the content of large volume nuclear waste and the Cavity Ring-Down Spectroscopy (CRDS) as an innovative technique to characterize outgassing of radioactive waste.

The implementation of digital technologies to improve key tasks in the decommissioning of nuclear facilities is the objective of the on-going H2020 Euratom projects PLEIADES H2020 and CLEANDEM H2020. BIM and Digital twins are being developed to add value and accelerate the decommissioning programmes. The on-going EU-funded CLEANDEM project[19] could cover some aspects related to the

[16] Research Publications Repository Link - EURAMET
[17] Instrumentation for cleaning and decommissioning - MICADO Project (micado-project.eu)
[18] CHANCE: Characterisation of conditioned radioactive waste | Chance H2020 (chance-h2020.eu)
[19] https://cordis.europa.eu/project/id/945335

highlighted needs. Indeed, Unmanned Ground Vehicle (UGV) Platform equipped with innovative radiological sensing probes, performing a radiological assessment of the area and then monitoring D&D operations throughout the final characterization of the plant. This will result in a 3D and fully detailed digital twin of the surveyed area augmented with radiological information provided by the sensors, thus enabling an efficient and effective planning of the dismantling actions and optimizing the nuclear waste sorting for reprocessing or for delivery to the final storage.

INSIDER H2020[20] developed a strategy for data analysis and sampling design for initial nuclear site characterization in constrained environments before decommissioning, based on a statistical approach. The STRATEGIST web tool[21] is a guideline to implement a data analysis and sampling design strategy for radiological characterization.

The Euratom Programme's objective of maintaining and enhancing the EU's nuclear competences is supported by some initiatives such as:

- The ENEN PLUS (ENEN+) Project[22], substantially contributes to the revival of the interest of young generations in the careers in nuclear sector. The main objectives are to attract new talents to careers in nuclear, develop the attracted talents beyond academic curricula, increase the retention of attracted talents in nuclear careers, involve the nuclear stakeholders within EU and beyond and sustain the revived interest for nuclear careers
- European Learning Initiative in Nuclear Decommissioning and Environmental Remediation (ELINDER[23]).

Finally, the IAEA and OECD NEA are sharing knowledge, good practices and technical information through their international networks and working groups such as International Decommissioning Network (IDN), the Environmental Management and Remediation network (ENVIRONET) and the NEA Expert Group on the Application of Robotic and Remote Systems in the Nuclear Back-end (EGRRS.)

[20] INSIDER – Improved nuclear site characterisation for waste minimisation in D&D operations under constrained environments (insider-h2020.eu)
[21] https://insider-h2020.sckcen.be/#introduction
[22] https://database.enen.eu/index.php/portfolio/enen-plus-project/
[23] https://ec.europa.eu/jrc/en/training-programme/elinder

Thematic Area 3: Management of Material and Radioactive Waste from Decommissioning

3.1 Introduction and Background

Decommissioning nuclear facilities produces a wide range of materials and wastes that require a range of management options. Some materials will be essentially un-contaminated and can be made available for reuse and recycling including for example some metal and concrete components. However other materials will be contaminated either chemically, radiologically or sometimes both requiring treatment/processing, and there will also be a range of radiologically contaminated wastes from VLLW to ILW requiring different waste routes for their packaging and storage/disposal.

The methods and procedures used to undertake decommissioning and material/waste management in this context can encompass a wide range of different strategies.

In general, it was highlighted that for the site management of material and radioactive waste from decommissioning, there is scope for much greater harmonisation in terms of guidance and waste management practice/procedure notably in terms of the application of Waste Acceptance Criteria (WAC) for storage and disposal and around the clearance of materials for reuse/recycling. Aqueous waste containing specific radiological contaminants and other problematic wastes are highlighted as a specific area for collaboration research and learning in terms of how they are managed and ultimately disposed of. Greater co-ordination and collaboration between parties undertaking decommissioning operations has the potential to drive a more consistent approach to materials and waste management leading to safer and more cost-effective management strategies.

3.2 Implementation of RD&D activities

The RD&D Implementation activities of common interest, highlighted in the SHARE project in the field of material and waste management are listed in the following section with the relative priorities (ranking importance) as identified in the SHARE weighted survey.

Thematic Area 3: Priority Activities					
Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q70 Management routes for materials including radioactive waste streams	Activity (1): Technical and non-technical actions to improve management of graphite mixed waste from decommissioning to disposal	Open routes for waste not covered by current WAC	INNO4GRAPH
			Activity (2): Technical and non-technical actions to improve management of contaminated toxic liquids and materials from decommissioning to disposal (see also Q86)	Open routes for waste not covered by current WAC	PREDIS
			Activity (3): Actions to encourage use of new developments to better manage waste flows from production to disposal (IT tools and other emerging technologies)	Industrial implementation of emerging technologies for waste treatment	
			Activity (4): Development, industrialisation and promotion of emerging solutions at lab scale for waste treatment (to optimise volume of waste to disposal)	Industrial implementation of emerging technologies for waste treatment	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH		Q81. Radioactive waste conditioning	Activity (1): Development to demonstrate long-term behaviour of geopolymers	Choice for best fit conditioning matrix and increase in TRL	PREDIS
			Activity (2): Actions to better master long-term performance, WAC and regulation - Need for demonstration	Choice for best fit conditioning matrix and increase in TRL	
			Activity (3): Benchmarking, development and guidance on solutions for reconditioning of historical waste already conditioned	Solutions for reconditioning of historical waste already conditioned	
			Activity (4): Development (R&D, softwares, etc.) to better master hydrogen evolution in matrices	Hydrogen production avoidance/prediction when conditioning reactive materials Safety improvement	
HIGH	02	Q82. Radioactive waste packaging and logistics	Activity (1): Actions to implement new developments for waste monitoring in storage facilities to better survey waste behaviour during storage	Benefit from technological advances in monitoring	CHANCE
			Activity (2): Development and use of shock absorbers for transportation packages made of reusable material instead of wood, etc.	Reuse of material	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH		Q84. Material clearance (methodology and procedures)	Activity (1): Benchmarking to create opportunities at the international level for recycling inside the nuclear sector	Enhance recycling of released materials	PREDIS
			Activity (2): Benchmarking at international level for cost with comparison of solutions (storage on sites, centralised depository, recycling in and out of nuclear sector		
			Activity (3): Actions to enhance recycling of metal (in and out of nuclear sector)		
			Activity (4): Development of processes and construction of metal melters to be able to process large items		
HIGH		Q86. Management of hazardous and toxic materials (asbestos, lead in paint etc)	Activity (1) State of the art and R&D to improve management of contaminated asbestos from decommissioning to disposal (See also Q70)	Treatment and evacuation routes for asbestos and PCBs with improved safety, minimised environmental impact and reduced cost	
			Activity (2): State of the art and R&D to improve management of PCBs (WAC etc.) (See also Q70)		
MEDIUM		Q73: Radioactive material treatment processes (metals)	Activity (1): Developments to simplify the handling of secondary waste from decontamination, fusion or other processing for metallic waste from decommissioning	Cost efficient secondary waste management	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q74. Radioactive material treatment processes (concrete)	Activity (1): R&D to demonstrate long term behaviour of irradiated/ activated concrete from decommissioning	Knowledge on long term behaviour	
MEDIUM		Q75. Radioactive material treatment processes (aqueous liquids)	Activity (1): New treatment paths for specific contaminants in liquid waste	Improve management of liquid waste with specific contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	PREDIS
			Activity (2): Developments to increase TRL and the more widely use of mineral adsorbents to replace organic resins for treatment of contaminated aqueous liquids (adsorbent directly disposable; e.g. trapping radionuclides under radiation, etc.)- see also Q70	Management of secondary waste from treatment of liquid waste	
MEDIUM		Q76. Radioactive material treatment processes (non aqueous liquids)	Activity (1): Demonstrate existing/new processes for treatment of organic liquids e.g. plasma under water etc. plus long term performances of innovative conditioning matrices	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics) contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	PREDIS
			Activity (2): Benchmarking in oil/gas or hazardous waste sector (non-nuclear)	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics)	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q77. Radioactive material treatment processes (organic materials)	Activity (1): Demonstrate already developed processes for treatment of organic liquids e.g. plasma under water, etc. and long term performances of innovative conditioning matrices	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics) contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	PREDIS
			Activity (2): Benchmarking in oil/gas or hazardous waste sector (non-nuclear)	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics)	
MEDIUM		Q79. Radioactive material treatment processes (LLLW)	Activity (1): Development of optimised processes for management of ashes produced during thermal processes of ILW	Improved management of ashes produced during thermal processes (LLW and ILW)	THERAMIN PREDIS
MEDIUM		Q80. Radioactive material treatment processes (ILW)	Activity (1): 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.)	Management of small waste quantities	THERAMIN PREDIS
			Activity (2): R&D and guidance to master impact of microbiological activity on waste stored in open ponds	Understand impact of microbiological activity on waste stored in open ponds	
MEDIUM	02	Q85. Material clearance (instrumentation and logistics)	Activity (1): Development of a characterisation platform to measure multi radionuclides directly for clearance (without need of nuclide vector)	Simplify and improve reliability of measurement of material prior to clearance	CHANCE METRODECOM

3.3 Crosscutting Activities

The related crosscutting activities identified in the field of Management of Material and Radioactive Waste from Decommissioning, included in the SRA TA03, are compiled in the following section. They are grouped into three main categories: knowledge sharing, education & training / competence development and harmonisation of practices.

Thematic Area 2: Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH	02	Q21. Tools for data collection in the field (e.g. for work monitoring)	Activity (1): Enhance use of IT tracking system for waste management	Data collection technology	
HIGH	05	Q84. Material clearance (methodology and procedures)	Activity (1): Share knowledge and feedback on actions related to societal issues/dialogues for acceptance of policy of recyling and reuse of material	Achievement of public/societal perception and acceptance Develop reliable outputs for recyclable materials	
HIGH		Q81. Radioactive waste conditioning	Activity (1): Best practices on choice of cement/ geopolymer/ vitrification for waste conditioning (LLW, ILW)	Choice for best matrix and increase in TRL	
			Activity (2): Best practices for conditioning of reactive materials including powdery ones	Avoid/Control hydrogen production when conditioning reactive materials	
HIGH	04	Q82. Radioactive waste packaging and logistics	Activity (1): Best practices on transportation of material for segmentation in the facility or on site	Transportation of material for segmentation in the facility or on site	

MEDIUM		Q73. Radioactive material treatment processes (metals)	Activity (1): Best practices on selection of processes for metallic material treatment, including secondary waste management	Cost efficient treatment of metallic material Simplify the handling of secondary waste from processing	
MEDIUM		Q75. Radioactive material treatment processes (aqueous liquids)	Activity (1): Best practices on existing routes and methodologies for management of liquid waste with specific contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	Improve management of liquid waste with specific contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	
			Activity (2): Best practices on use of mobile installations for treatment of liquid effluents	Management of small volumes of diverse wastes	
MEDIUM		Q77. Radioactive material treatment processes (organic materials)	Activity (1): Techno-economical comparative analysis and best practices on various options for solid organics including local mobile solution versus big centralised facilities depending on waste streams (variety, quantity, activity, etc.)	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics)	

HARMONISATION OF PRACTICES

Ranking	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH	04	Q13. Development /National regulatory guidance for Decommissioning: Clearance of structures and materials	Activity (1): Guidance to improve the existing Clearance Criteria (values are missing for some isotopes in DIRECTIVE 2013/59/EURATOM and defined scenario for liquids)	Complete existing Clearance Criteria for missing radionuclides and liquid radioactive materials	

Ranking	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q73. Radioactive material treatment processes (metals)	Activity (1): Guidance to enhance co-ordination between waste producers and operators of melting systems (on requirements, on decontamination place, etc.)	Guidance	
MEDIUM			Activity (2): Actions to enhance harmonisation of practices for treatment of VLLW metallic waste, including recycling	Harmonisation of practices	
MEDIUM		Q76. Radioactive material treatment processes (non aqueous liquids)	Activity (1): State of the art, comparative analysis and guidance on various options for liquid organics including local mobile solutions versus big centralised facilities	Optimise management of organic liquids	
MEDIUM			Activity (2): 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	Implement solutions developed in laboratories with engagement of all actors (for all waste, not only organics)	
MEDIUM		Q79. Radioactive material treatment processes (LLW)	Activity (1): Guidance on methodologies and strategies in the choice of treatment process for LLW waste (efficiency, de-categorization, volume reduction, compliance with WAC, etc.	Provide guidance on decision making on process/ treatment and categorisation	
			Activity (2): Guidance to improve management of broken packages	Improve risk management and limit environmental impact	

Ranking Importance	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q80. Radioactive material treatment processes (ILW)	Activity (1): Guidance on methodologies and strategies in the selection of treatment process for ILW waste (efficiency, de-categorisation, volume reduction, compliance with WAC, etc.) for better, safer and cheaper results	Decision making process / Treatment and categorisation of waste	
	02	Q84. Material clearance (methodology and procedures)	Activity (1): Actions to harmonise good practices in recycling of released materials	Enhance recycling of released materials	
HIGH	04	Q82. Radioactive waste packaging and logistics	Activity (1): 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?	Optimise packaging solutions (from decom, transportation, storage to disposal)	
MEDIUM		Q74. Radioactive material treatment processes (concrete)	Activity (1): Actions to enhance harmonisation of practices for treatment of VLLW concrete waste, including recycling	Harmonisation of practices	
MEDIUM		Q75. Radioactive material treatment processes (aqueous liquids)	Activity (1): Actions to enhance harmonisation of practices in the regulation for authorised release levels in operation and in decommissioning phases (for boron, tritium, etc.)	Improve management of liquid waste with specific contaminants (tritium, 14C, boric acid, colloids, mixed waste, etc.)	
MEDIUM		Q78. Radioactive material treatment processes (VLLW)	Activity (1): Actions to enhance harmonisation of practices in VLLW management	Improve management of VLLW waste	

Ranking Importance	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM	01	Q10. International harmonisation of safety standards and safety approaches for Decommissioning	Activity (1): Actions to enhance international harmonisation of WAC in terms of policy and regulation, in coordination with[24] IAEA, NEA, WNA, WENRA, ENSREG, etc.	International standardisation for safety requirements	
			Activity (2): Actions to enhance international harmonisation of clearance criteria for Solid/Liquid/Gaseous radioactive materials from decommissioning	International standardisation for definition of WAC and Clearance	
MEDIUM	01	Q70. Management routes for materials including radioactive waste streams	Activity (1): Identify other needs and coordinate with ROUTES and PREDIS	Open routes for waste not conform present WAC	
			Activity (2): Actions to enhance harmonisation of practices in VLLW management (metal, concrete etc.) regarding clearance and acceptance criteria	International harmonisation on management of waste transportation, standardisation and packaging	
			Activity (3): Actions to define strategy and promote international sharing of facilities for treatment or storage of waste from decommissioning	International harmonisation on management of waste transportation, standardisation and packaging	
			Activity (4): Actions to enhance harmonisation of practices in packaging (transport, storage, disposal)	International harmonisation on management of waste transportation, standardisation and packaging	

[24] WNA, WENRA, ENSREG : World Nuclear Association, Western European Nuclear Regulators' Association, European Nuclear Safety Regulators Group

3.4 Ongoing Initiatives and Recent Activities

With the purpose of sharing experiences and knowledge on decommissioning and radioactive waste management issues, different International initiative were launched in the past years by IAEA and NEA.

The ongoing initiatives addressing the WM&D activities topics include:

- IAEA's Specific Safety Guide No. SSG-40 - Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors.
- IAEA-TECDOC-1817 - "Selection of Technical Solutions for the Management of Radioactive Waste", 2017.
- IAEA-TECDOC-1130 - "Recycle and Reuse of Materials and Components from Waste Streams of Nuclear Fuel Cycle Facilities," 2000.
- The Nuclear Energy Agency (NEA) Working Party on Decommissioning and Dismantling (WPDD)
- NEA's Recycling and Reuse of Materials (TGRRM Task Group)

There are some EC Horizon-2020 projects that contribute to address some specific challenges in the WM&D thematic Area:

- PREDIS project - Predisposal Management of Radioactive Waste targeting innovation and break-through technologies for safer, more efficient, more economic, and more environmentally-friendly handling of ILW/LLW radioactive wastes.
- THERAMIN project - Thermal treatment for radioactive waste minimisation and hazard reduction to provide improved safe long-term storage and disposal of intermediate and low level radioactive waste streams.
- CHANCE project - Characterisation of Conditioned Nuclear Waste for its safe Disposal in Europe.
- MICADO project - Measurement and Instrumentation for Cleaning And Decommissioning Operations.
- ELINDER project - Modular, coherent and commonly qualified training programme in nuclear decommissioning.

Additionally, in 2019, the 'Waste Management & Decommissioning Working Group' of the WNA produced a report[25] bringing together knowledge and expertise in this area and providing guidance to those facing new decommissioning challenges.

[25] Methodology to Manage Material and Waste from Nuclear Decommissioning, WNA Waste Management & Decommissioning Working Group, 2019

Thematic Area 4: Site Preparatory Activities, Dismantling, Decontamination and Demolition

4.1 Introduction and Background

Dismantling of nuclear facilities involves tasks of decontamination of components and concrete structures, segmentation/cutting of metallic components (vessels, internals, tanks, piping, pumps, etc.) and demolition of large reinforced structures as well as management, handling, and segregation of segmented elements.

Before starting the actual dismantling, preparatory activities should be organised in various ways depending on considered decommissioning strategies, physical and radiological status of the nuclear facility after its routine operation is over, type of facility and regulatory regime. They typically include the conversion of auxiliary systems for decommissioning, preparation of infrastructures including storages and buildings for decommissioning, and internal system decontamination.

In general, it was highlighted[26] that for the Site Preparatory Activities, technologies are already available and mostly well-developed but there is still the opportunity for further developments in terms of automation in monitoring[27], use of mobile infrastructure for waste management[28] and development of innovative technologies for the handling of liquid waste produced during internal system decontamination[29]. Those specific activities are mainly related to the fields of Characterisation and Radioactive Waste Management and are discussed in the relevant sections (TA02 and TA03).

During the actual dismantling of nuclear facility components and structures, various techniques are involved. Most of them are already available and used, with new and less labour intensive techniques being developed continually. The 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.

Actions related to state of the art machinery, benchmarking, improvement and innovation in existing and new dismantling technologies could bring significant opportunities in terms of strategy optimisation, technology effectiveness and efficiency, life-cycle performances and secondary waste minimisation. Moreover, improvement in safety of the workers (in terms of minimising dose rate) could be achieved by introducing automation of procedures, digitalisation, robot and remote-control dismantling techniques and 3D models and simulations. A focus on semi-autonomous solutions combining advanced robotics with virtual reality and artificial intelligence can thereby support safe and effective nuclear facility decommissioning.

[26] SHARE D3.2: Technology assessment/ gap analysis report https://share-h2020.eu/project-deliverables/
[27] Referred to Q47. Adaption of auxiliary systems for decommissioning (ventilation, electrical, monitoring, etc.): linked to Q53. In situ radioactive waste characterisation and segregation, discussed in TA 02
[28] Referred to Q48. Preparation of infrastructures and buildings for decommissioning (storages, capabilities for material sorting and treatment...): linked to Q73. Radioactive material treatment processes (metals), discussed in TA 03
[29] Referred to Q49. Systems decontamination (internal): linked to Q75. Radioactive material treatment processes (aqueous liquids) and Q76. Radioactive material treatment processes (non aqueous liquids), discussed in TA 03

4.2 Implementation of RD&D activities

Thematic Area 4: Priority Activities					
Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q60. Robots and remote controlled tools for dismantling	Activity (1): Development of new cost-effective and more general purpose modular and mobile systems and robotic solutions for different dismantling tasks	Improvements in modular and mobile solutions. Increase efficiency in dismantling tasks	
			Activity (2): Development and update of an easy to access database that provides information on evaluated robotics for different tasks in decommissioning	Enhance the use of robotic systems	
			Activity (3): Enhance in the use and interoperability of digital technologies to assist the workers' training and the modelling and simulation of dismantling alternative scenarios	Digitalisation for advancement in systems and overall reduction of the project duration and cost	PLEIADES
			Activity (4): Development of technologies and methodologies for hard to access areas with improvements in tele-operated remote arms	Flexibility and efficiency in the use of robotic systems for specific circumstances	
			Activity (5): Development of testing methodologies for robotics in mock-ups	Advantages in safety and standardisation	INNO4GRAPH

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
HIGH		Q51. Segmentation of large irradiated metallic components (reactor vessel internals, etc.)	Activity (1): Development of a pre-segmentation strategy (i.e. towards decontamination)	Segmentation strategy optimisation	
			Activity (2): Integration of remote control dismantling techniques with 3D models & simulations	Innovative remote autonomous techniques	PLEIADES – INNO4GRAPH
			Activity (3): Benchmarking of the state of the art on long reach manipulators with greater dexterity	Innovative remote autonomous techniques	
HIGH		Q57. In situ decontamination of building surface (concrete)	Activity (1): Development of scanners and detectors to select best approach for decontamination	Inventory assessment before the selection of decontamination technique	CLEANDEM
			Activity (2): Benchmarking of technologies and methodologies for in-situ decontamination with good efficiency and minimised secondary waste production	Improvements in techniques that limits secondary waste	
MEDIUM		Q52. Handling, segregation and loading of segmented elements and secondary waste	Activity (1): Development of (semi-)automated handling, segregation and packaging systems	Optimisation of the handling, segregation and packaging tasks	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q74. Radioactive material treatment processes (concrete)	Activity (1): Benchmarking and development of decontamination techniques with the implementation of remote operations	More efficient decontamination techniques in terms of efficiency and dust collection	
MEDIUM		Q71. Mechanical radioactive material decontamination	Activity (1): Laser decontamination technology benchmarking considering secondary waste minimisation and efficiency	Improvements in already available technologies (e.g. laser decontamination) considering secondary waste minimisation and efficiency	
			Activity (2): Benchmarking of remote systems with integrated characterisation and decontamination equipment	Innovative remote systems for decontamination	
LOW		Q72. Electrochemical radioactive material decontamination	Activity (1): Improvements and research activities are needed to develop innovative solutions in electrochemical decontamination	Innovative solutions in electrochemical decontamination	
	03		Activity (2): Guidance of the development of new conditioning approach (new waste form) or for the optimisation of waste forms from electrochemical decontamination according to WAC	Optimised waste forms	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
LOW		Q55. Dismantling of surface-contaminated piping and small components	Activity (1): Development in technology for already existing pipe cutting technologies that provide secondary waste minimisation and good rate	Innovative cutting techniques	
			Activity (2): Development of technologies and methodologies for hard to access piping for surveying and segmentation	Innovative cutting techniques	
			Activity (3): Development of innovative cutting techniques towards industrialisation (i.e. electrochemical cutting to consider decommissioning specificities)	Innovative cutting techniques	
LOW		Q59. Demolition of large, reinforced concrete structures	Activity (1): Benchmarking for laser technology considering secondary waste minimisation and efficiency	Innovation and improvements in laser technology	
			Activity (2): Research activities in laser technology considering micro melting phenomenon	Innovation and improvements in laser technology	

4.3 Crosscutting Activities

Thematic Area 4: Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q60. Robots and remote controlled tools for dismantling	Activity (1): Sharing of experiences and best practices for efficient remote cutting technologies	Improvements in defining robotic solutions for specific circumstances	
HIGH		Q51. Segmentation of large irradiated metallic components (reactor vessel internals, etc.)	Activity (1): Dissemination and sharing of experiences and best practices for selection and optimisation of segmentation strategy	Guidance for the selection and optimisation of segmentation strategy for large irradiated metallic components considering different technical, environmental and economic factors. Enhance the efficiency and effectiveness of the segmentation task	
HIGH	03	Q82. Radioactive waste packaging and logistics	Activity (1): Dissemination and sharing of best practices and standard safety case	Guidance on the definition of standard safety case for transportation of material for segmentation in the facility or on site	
MEDIUM		Q58. Management (characterization, decontamination, removal) of radiological embedded elements	Activity (1): Dissemination of best practices and knowledge improvements on management of embedded waste	Guidance on methodologies for the separation of embedded elements (e.g. metals in plastic) in order to obtain a final disposal route in line with the regulatory constraints	

Ranking Importance	TA Link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q54. Segmentation of large surface-contaminated components	Activity (1): Sharing experiences and best practices for segmentation strategy for large surface-contaminated components that are compatible with decontamination techniques	Improve knowledge and optimise the selection of the segmentation strategy	
			Activity (2): Sharing of experiences and best practices for efficient technologies for segmentation of large surface-contaminated components	Guidance on cheaper and safer technology that minimises the secondary waste during segmentation	
MEDIUM		Q56. Segmentation of interior concrete structures (e.g., bioshield)	Activity (1): Dissemination and sharing of experiences for already implemented technologies for interior concrete structures and biological shield segmentation	Development of competence and knowledge in concrete segmentation techniques	
LOW		Q59. Demolition of large, reinforced concrete structures	Activity (1): Sharing of experiences and best practices for safer techniques for the demolition of large, reinforced concrete structures	Guidance for the selection of a demolition strategy and for the identification of safety references	

EDUCATION& TRAINING / COMPETENCE DEVELOPMENT					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
LOW		Q59. Demolition of large, reinforced concrete structures	Activity (1): Education and Training programmes and guidance for the use of remote demolition techniques	Increasing worker safety and development of safety reference	
HARMONISATION OF PRACTICES					
Ranking Importance	**TA Link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
HIGH		Q60. Robots and remote controlled tools for dismantling	Activity (1): Identification of Member States' different approaches for the safety case definition	Alignment and harmonisation of safety case definition approaches, improvements in safety concerns and enhancement in confidence for regulatory authorities and operators on the use of robotic systems	NEA EGRRS
			Activity (2): Identification of Member States' standards for robotics verification and demonstration	International standardisation on procedures for robotics verification and demonstration	
HIGH		Q51. Segmentation of large irradiated metallic components (reactor vessel internals, etc.)	Activity (1): Identification of the Member States' different safety and demonstration approaches for the use of innovative remote autonomous tools for RPV segmentation	Harmonisation of safety and demonstration approaches on the use of innovative remote autonomous tools for RPV segmentation. Enhancing the confidence for regulatory authorities and operators	

			Activity (2): Guidance on methods for the Life Cycle Cost evaluation of the segmentation equipment	Innovative remote autonomous techniques for segmentation	
MEDIUM		Q74. Radioactive material treatment processes (concrete)	Activity (1): Guidance on the assessment of the failure mode and the life cycle of the equipment	More efficient decontamination techniques	
MEDIUM		Q71. Mechanical radioactive material decontamination	Activity (1): Guidance on the life-cycle assessment of decontamination systems	Innovative remote systems for decontamination	

4.4 Ongoing Initiatives and Recent Activities

With the objective of sharing experiences and knowledge on decommissioning and radioactive waste management issues, different international initiatives have been launched in the past years by IAEA and NEA.

The ongoing initiatives addressing the Dismantling and Site Preparatory activities topics include:

- NEST ARTERD Project (led by JAEA/CLADS and the University of Tokyo) that is dedicated to advanced remote technology for decommissioning under intense gamma-ray radiation environments (e.g. robotics, virtual reality).
- An agreement signed in September 2021 (valid until 2025) where the IAEA designated the EDF DP2D Graphite Reactor Decommissioning Demonstrator as an IAEA Collaborating Centre. The demonstrator will be used to enable international cooperation, knowledge transfer between generations and to train and qualify the operators for decommissioning nuclear power reactors that contain significant amounts of irradiated graphite.
- NEA Expert Group on the Application of Robotic and Remote Systems in the Nuclear Back-end (EGRRS) which advises member countries on the leading and emerging issues that focuses on the development of strategic approaches to facilitate the implementation of robotic and remote systems (RRS) in radioactive waste management, decommissioning and legacy management at national and international levels.

There are some EC Horizon-2020 projects that address some specific challenges in the Dismantling Thematic Area:

- PLEIADES project (PLatform based on Emerging and Interoperable Applications for enhanced Decommissioning processes) aims to develop a new methodology for improving dismantling and decommissioning (D&D) operations in Europe by integrating cutting-edge digital support tools into a Building Information Modelling (BIM) technology-based platform. It will also be capable of retrieving and connecting data and calculating simulation results regarding scenario feasibility, waste estimation, radiation exposure, cost and duration.
- INN4OGRAPH project (INNOvative tools FOR dismantling of GRAPHite moderated nuclear reactors) will develop a set of tools and methods for dismantling graphite moderated nuclear reactors. Specifically, it will enable 3D modelling of dismantling scenarios as well as measurement tools for mechanical and physical properties. The project's tools and methods will be put to the test at a full-scale graphite power plant demonstrator in Chinon (France) facilitating their uptake and further development.
- LD-SAFE project (Laser Dismantling Environmental and Safety Assessment) aims to validate the laser cutting technology for the dismantling of the most challenging components of power nuclear reactors in air and underwater.
- CLEANDEM project (Cyber physicaL Equipment for unmAnned Nuclear DEcommissioning Measurements) aims to realize a fully functional combination of tools that can be easily integrated into unmanned ground vehicles (UGVs) to be utilized in different D&D and clean-up scenarios where different types of radiological characterization are required to obtain the best possible radiological information necessary to support dismantling operations.

Thematic Area 5 & 6: Environmental Remediation & Final Survey and Release from Regulatory Control

5.1 Introduction and Background

Environmental Remediation aims to reduce radiation exposure from soil and groundwater contamination that results from past activities involving the use of radioactive material. It is generally considered as the last step in nuclear decommissioning because it prepares the site for its next use eliminating ongoing contamination processes.

Environmental remediation involves different technologies and methodologies with the final goal of returning a site to the conditions that prevailed before the contamination and/or in compliance with the national legal and regulatory requirements.

Environmental remediation involves many challenges including technological and safety challenges. They are mainly related to:

- the characterisation methods and technologies needed in the problem definition phase (to determine the exact nature of the problem or if a response in terms of remediation is even required) and in the final release phase (to verify the clearance levels);
- the technologies and methodologies applied during the implementation phase to remove/reduce to acceptable level the contamination.

The Environmental Remediation subthematic area covers methodologies and techniques for clearance of surface and structure, characterisation methods for subsurface contamination, modelling and statistical tools to analyse contaminant transport in subsurface soil and groundwater, soil remediation technologies and remediation of contaminated groundwater.

The technical and non-technical challenges and needs highlighted in the SHARE gap-analysis (D3.2) and prioritised according to the weighted analysis conducted (D2.5) are mainly related to:

- characterization methods and technologies used during the different phases of the process, from the initial problem definition phase to the final release phase[30];
- technologies and methodologies applied during the implementation phase to remove/reduce to acceptable level the contamination;
- knowledge sharing about methodologies, technologies and best practices.

[30] Linked to Q62. Clearance of surfaces and structures (interiors and exteriors) and Q63. Characterisation methods and technologies to identify subsurface contamination, discussed in TA 02

The survey for the Final Release of the Site, also called final status survey, is the last step of a series of surveys designed to demonstrate compliance with a dose- or risk-based regulation for sites with radioactive contamination. There are four phases in the final status survey: planning, implementation, assessment and decision-making.

The assessment phase includes verification and validation of the survey results combined with an assessment of the quantity and quality of the data. Both the average level of contamination in the survey unit and the distribution of the contamination within the survey unit are considered during area classification. For this reason, the assessment phase includes a graphical review of the data to provide a visual representation of the radionuclide distribution, an appropriate statistical test to demonstrate compliance for the average concentration of a uniformly distributed radionuclide, and the high measurement comparison (HMC) to demonstrate compliance for small areas of high activity.

Many reference documents and standards are available to provide guidance on the release of sites or parts of sites from regulatory control after a practice has been terminated.[31],[32],[33],[34],[35],[36]

The subthematic areas which refer to Final Survey and Release from Regulatory Control deal with methodologies and techniques for the final release survey of the site and related tools for statistical analysis and management of the survey data.

The needs highlighted are mainly related 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.

[31] NUREG-1757, Vol.2 Rev.1, "Consolidated Decommissioning Guidance: Characterisation, Survey, and Determination of Radiological Criteria", September 2006
[32] IAEA Safety Guide No. WS-G-3.1, Remediation Process for Area Affected by Past Activities and Accidents, 2007
[33] IAEA Safety Guide No. WS-G-5.1, Release of Sites from Regulatory Control on Termination of Practices, 2006
[34] IAEA Technical Reports Series No. 424, Remediation of Sites with Dispersed Radioactive Contamination, 2004
[35] NEA-OECD No. 7290, Strategic Considerations for the Sustainable Remediation of Nuclear Installations, 2016
[36] ISO 18557:2017 Characterisation principles for soils, buildings and infrastructures contaminated by radionuclides for remediation purposes

5.2 Implementation of RD&D activities – TA 05 Environmental Remediation

Thematic Area 5: Priority Activities					
Implementation RD&D					
Ranking Importance	**TA link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q64 Modelling and statistical tools to analyse contaminant transport in subsurface soil and groundwater	Activity (1): Development of digital tools to better understand the contaminants transport in the soil and groundwater systems	Improvements in accuracy of predictive modelling to assess the migration of contaminants	
MEDIUM		Q65. Soil remediation technologies (washing, bioremediation contamination fixing)	Activity (1): Development of multi-criteria decision-making approaches/techniques considering cost, end state and environmental protection	Optimisation in the decision making towards soil remediation technologies	
			Activity (2): RD&D activities to improve existing technologies already implemented in soil remediation	Improvements in capabilities of the soil remediation technologies reducing time and costs	
			Activity (3): Development of integrated solutions for remediation and characterisation technologies through coordination between different market stakeholders and suppliers	Improvements in the execution of the remediation activities	

Ranking Importance	TA link	Subthematic Area	Activities	Expected Outcome & Impact	Ongoing Activities
MEDIUM		Q66. Remediation of contaminated groundwater (radiological)	Activity (1): Development of large-scale technologies or mixed technologies both for remediation and prevention to manage a post accidental contamination environmental effect.	Innovative technologies to address post-accident contamination	
			Activity (2): Benchmarking of technologies for remediation and prevention of any contamination or their spread into the environment	Innovative technical solutions for ground water remediation to reduce contaminant concentrations in groundwater and to prevent any contamination/diffusion	
			Activity (3): Development of innovative water monitoring technologies for in-situ real time measurements	Improvements in technology for on-line radiological monitoring of groundwater	
			Activity (4): Development of bioremediation technologies for groundwater remediation	Innovative and sustainable technologies for groundwater remediation	

5.3 Crosscutting Activities related to TA 05 Environmental Remediation

Thematic Area 2 Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Subthematic Area**	**Activities**	**Expected Outcome & Impact**	**On-going Activities**
MEDIUM		Q64 Modelling and statistical tools to analyse contaminant transport in subsurface soil and groundwater	Activity (1): Dissemination and sharing of experience among the stakeholders	Enhance and improve the use of predictive models used to estimate radionuclide behaviour in the longer term for model building and long term follow-up	
MEDIUM		Q65. Soil remediation technologies (washing, bioremediation contamination fixing)	Activity (1) Dissemination of soil remediation technologies	Networking to promote harmonization of technologies which can be applied	IAEA ENVIRONET

5.4 Crosscutting Activities related to TA 06 Final Survey and Release from Regulatory Control

Thematic Area 6 Priority Crosscutting Activities					
KNOWLEDGE SHARING					
Ranking Importance	**TA Link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
LOW		Q68. Tools for statistical analysis and management of survey data for site release	Activity (1): Dissemination and sharing of best practices	Guidance on existing IT tools available for statistical analysis and management of survey data for site release	
HARMONISATION OF PRACTICES					
Ranking Importance	**TA Link**	**Sub thematic Area**	**Activities**	**Expected Outcome & Impact**	**Ongoing Activities**
MEDIUM		Q67. Methodologies and techniques for final release survey of the Site	Activity (1) dissemination, sharing of experience and harmonisation among the stakeholders to identify differences regarding methodologies and technologies	Alignment and harmonisation on the release of sites or parts of sites from regulatory control and development of guidance on the definition of final end-state or the future of the site.	IAEA COMDEC

5.5 Ongoing Initiatives and Recent Activities

TA 05 Environmental Remediation

IAEA ENVIRONET (Network on environmental remediation)

“Lessons Learned from Environmental Remediation Programmes”: Lessons learned regarding technical aspects of remediation projects are reviewed. Techniques such as the application of cover systems and soil remediation (electrokinetics, phytoremediation, soil flushing, and solidification and stabilisation techniques) are analysed with respect to performance and cost.

“Remediation of Sites with Mixed Contamination of Radioactive and Other Hazardous Substances”, IAEA Technical Report Series No. 442

The DEMETERRES project (CEA) develops innovative and environmentally friendly methods for removal of cesium and strontium from soils and liquid matrices in order to rehabilitate them for an agricultural use while minimising the volume of generated wastes.

Operational experience and sharing of best practices can be obtained through on-going projects with regard to soil and environmental remediation:

> “Effectiveness of landscape decontamination following the Fukushima nuclear accident: a review”, SOIL Scientific Journal, 2019
>
> “Operational experience of the soil washing plant at the dismantling of the José Cabrera nuclear power plant”, ENRESA, Radioproteccion, 2020 (original: Spanish)

TA 06 Final Survey and Release from Regulatory Control

IAEA International Project on Completion of Decommissioning (COMDEC)

A new IAEA-led initiative to support national authorities in the decommissioning of shutdown nuclear power plants and other nuclear installations was launched in September 2018 and now is ongoing with Technical Meetings.

The three-year project will result in a systematic overview of the global experience in:

- defining the desired final status of decommissioning
- demonstrating compliance with end-state criteria
- defining and implementing any necessary measures and controls after the end of decommissioning

One of COMDEC working groups deals with regulatory aspects, including release of sites and institutional controls.

The project will provide input for the future revision of the IAEA Safety Guide WS-G-5.1 "Release of Sites from Regulatory Control on Termination of Practices".

Way Forward

This SRA compiles and organises the output from the gap analysis which has been performed in the scope of the SHARE project. It proposes research priorities, and suggests targets that can be achieved in the field of decommissioning aimed at safety improvement, environmental impact minimisation and cost reduction. The SRA considers research and innovation activities in the field of decommissioning based on the consultation of relevant stakeholders of different types and origin.

The SRA identifies knowledge gaps and defines and prioritizes research topics based on the weighted survey analysis. In addition to innovation and technological challenges, it also addresses non-technological issues in the fields of planning, costing, knowledge management and exchange of best practices.

The SHARE roadmap with the topics identified in the SRA will be developed for the forthcoming 10-15 years. The goal of the roadmap is to further review and organise these actions in such way that those relevant for joint activities are addressed in a timely manner, also based on the weighted survey analysis using the urgency ranking.

Suggestions for implementation and deployment for this roadmap will also be provided using the input from identification of international collaborative research initiatives[37].

[37] SHARE D3.3 Report identifying and comparing international collaborative research initiatives – Public Deliverable

Annex

SHARE strongly involved a wide range of stakeholders by consultation at different stages through the project. Stakeholders' opinions have been collected during the SHARE survey, a questionnaire on decommissioning needs divided into 8 thematic areas and 71 subthematic areas (Q=Questions).

An impartial, balanced and reliable assessment[38] of their feedback allowed for a ranking in terms of importance and urgency for all (sub)thematic areas. High, Medium and Low priorities have been set according to specific ranges for both criteria.

The outcome of the performed gap analysis[39] – comparing survey results with the state-of-art and available solutions - in all these thematic areas led to a list of proposed actions to fill the gaps identified for each subthematic area.

This prioritisation according to importance is also used to organise the research topics linked to each subthematic area in this SRA. The urgency aspect will be further used in developing the roadmap. Linking the eight major thematic areas from the survey to the different phases of a decommissioning project led to the identification of six major themes (see Introduction), as withheld in this SRA.

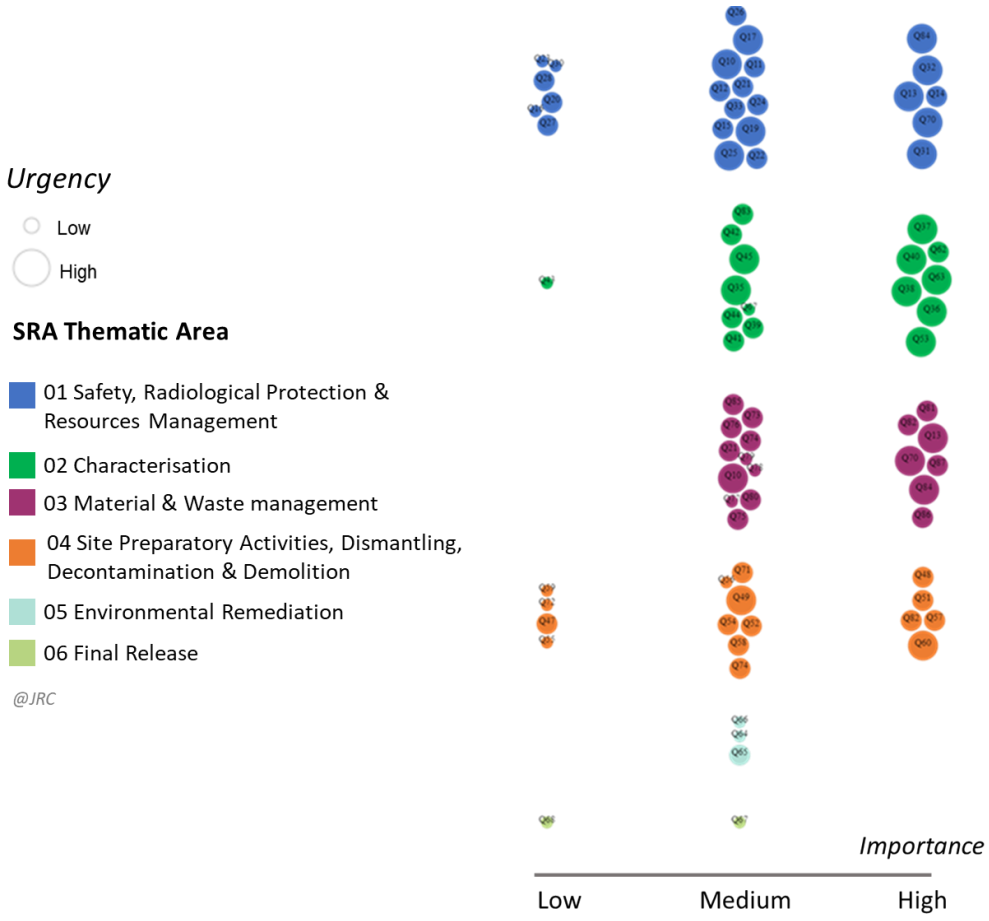

Figure 3 : Ranking of Survey's Subthematic Areas according to Importance and Urgency for the SRA Thematic Areas

[38] SHARE D2.5 Matrix and Explanatory Report from Task 2.3 – Public Deliverable

[39] SHARE D3.2 Technology Assessment / Gap Analysis Report – Public Deliverable