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Assessment of nuclear decommissioning technologies using gap analysis

M.J. Chaudhry[1], S. Müller[1], A. Bohnstedt[1], S. Gentes[1], C. Georges[2], L. Aldave De Las Heras[3], E.G. Neri[4], A. Banford[5], K. Van Den Dungen[6]

[1] Karlsruhe Institute of Technology (KIT), Germany

[2] Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), France

[3] Joint Research Centre (JRC), European Commission

[4] Empresa Nacional de Residuos Radiactivos (ENRESA), Spain

[5] National Nuclear Laboratory (NNL), United-Kingdom

[6] Centre d'étude de l'énergie nucléaire (SCK-CEN), Belgium

Corresponding Author: *muhammad.chaudhry@kit.edu*

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Introduction

Nuclear decommissioning is the final phase in the life cycle after construction, commissioning, and operation. It is a multifaceted process involving operations such as detailed surveys, decontamination, and dismantling of plant equipments and facilities, demolition of buildings and structures, and management of resulting waste, whereas taking into account aspects of safety, health and protection of the environment, education and training, communication with public, etc. Therefore, an enormous amount of capital is estimated to be required to decommission nuclear facilities in the coming decades. In order to highlight the fact, the nuclear decommissioning service market in Europe was valued at US$ 2.68 billion in 2019 and is projected to reach US$ 4.29 billion by 2027[1]. This leads to increased awareness and interest among a variety of stakeholders, like operators, industry, regulators, waste management companies, research organisations, universities, international organisations, consultants, and others.

The Horizon 2020 SHARE[2] project is funded by the European Commission with a primary objective to provide an inclusive roadmap for joint near future decommissioning research for stakeholders to improve safety, reduce costs, and minimise environmental impact in the decommissioning of nuclear facilities. The Research areas are focused on Research & Development, Research & Innovation, new methodologies, standards, and cross-cutting technologies in technical and non-technical areas. By the end of 2021, the aim is to develop a Strategic Research Agenda (SRA) associated with a Roadmap for the next 10-15 years to generate knowledge on decommissioning and its safety, economic, and environmental aspects. It aims to encourage the future coordination of research topics that are recommendable for financing in the next decade. Moreover, it will facilitate access to expertise and technology and maintain competencies in decommissioning and environmental remediation for the benefit of Member states in Europe and beyond.

1ResearchAndMarkets.com „Business wire, "03 February 2021. [Online]. Available: https://www.businesswire.com/news/home/20210203005497/en/Europe-Nuclear-Decommissioning-Service-Market-Forecast-to-2027-COVID-19-Impact-and-Analysis-by-Reactor-Type-Strategy-Application-Capacity-and-Country---ResearchAndMarkets.com. [Zugriff am 25 May 2021].

[2]"Stakeholder-based Analysis of Research for Decommissioning," H2020 project number 847626, https://share-h2020.eu/

Preview of project

The SHARE vision is to provide an inclusive roadmap for joint near future decommissioning research for stakeholders to improve safety, reduce costs and minimize environmental impact in the decommissioning of nuclear facilities. The overall approach of the SHARE project is based on a consultation process considering the needs and points of view of different stakeholders involved in the decommissioning value chain across the world. Three groups of stakeholders are involved: SHARE consortium members[3], an Expert Review Panel (ERP) including industry, operators, waste management organisations, research institutes, regulators beyond Europe with an interest of contributing to the process of establishing the roadmap by assessing, reviewing and complementing the overall outcome at different steps. Finally, a wider community of organisations across the decommissioning value chain who showed interest to SHARE initiative (answered to surveys or registered to public workshops and/ or to social media, etc.). An overview of SHARE methodology highlighting different work packages is shown in Figure 1[4].

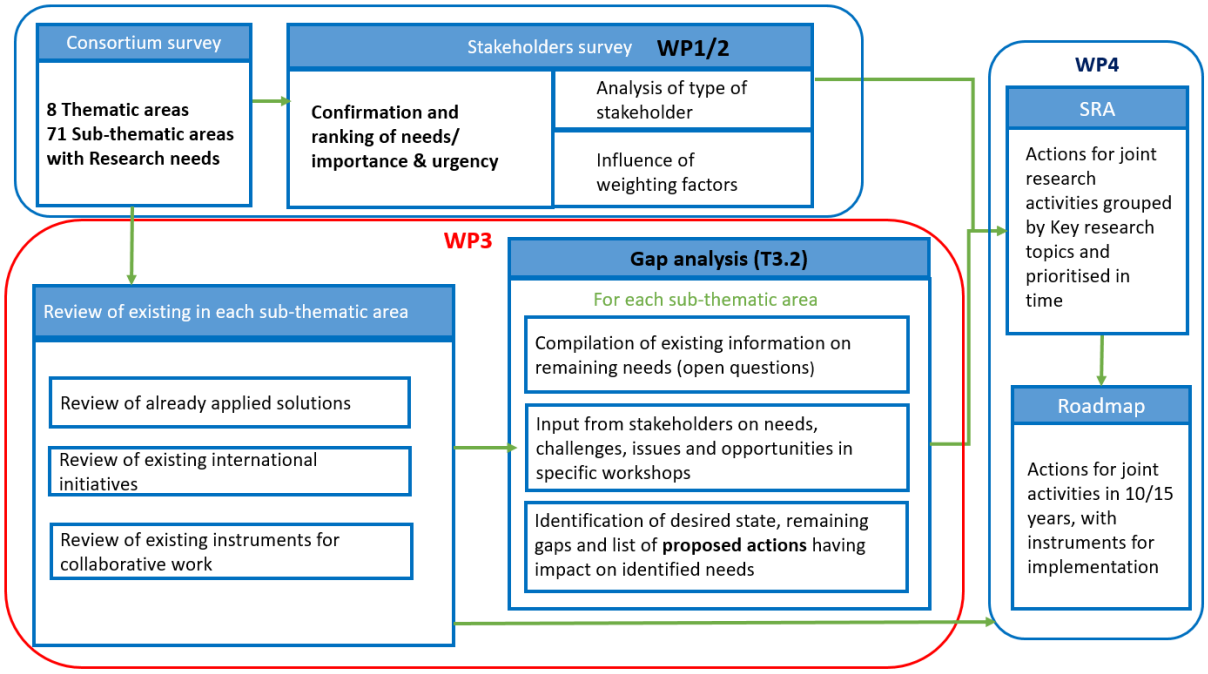

Figure 1: SHARE project methodology

To give a general overview of the project, WP1 and WP2 set up the methodology and organised a consultation process taking into account the needs and points of view of different stakeholders involved in the decommissioning. The survey on decommissioning research needs was conducted by the SHARE consortium from end of March to July 2020. The survey covers 8 thematic areas, each one grouping several predefined sub thematic areas. 71 sub-thematic areas were covered by the survey. Detailed results and analysis of the SHARE survey are presented in another article of this conference, providing general overview of the SHARE project[5].

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[3] SHARE consortium including CEA (FR), EI (FR), ENRESA (ES), EPRI (USA), IFE (NO), JRC (EU), KIT (DE), LEI (LT), NNL (UK), SCK-CEN (BE), SOGIN (IT), and VTT (FI).

[4] C. Georges, A. Banford, E. G. Neri, L. Aldave-De-Las-Heras und J. B. Linan, „European Project "SHARE":Stakeholders-based Analysis towards More Collaborative Projects of Research for Decommissioning – 21045," in *WM2021 Conference*, Phoenix, Arizona, USA, 2021.

[5] R. Winkler, F. Fert, C. Georges, L. Aldave De Las Heras, M.J. Chaudhry, E.G. Neri, J.L. Borque, A. Banford, K. Van Den Dungen, F. Pancotti, R. Svoke, I. Szoke, G. Poskas, A. Leskinen, P. Joly, "European Project "SHARE" Stakeholders-based Analysis towards More Collaborative Projects of Research for Decommissioning-," in SFEN-DEM2021 Conference, Avignon, France, 2021"

Table 1 : List of thematic areas

ID	Thematic areas
Q1	Safety and radiological protection aspects
Q2	Project management and costing
Q3	Human resources management
Q4	Characterisation during decommissioning
Q5	Site preparatory activities
Q6	Dismantling technologies
Q7	Environmental remediation and site release
Q8	Management of material and radioactive waste from decommissioning

In parallel, within the scope of WP3, a detailed review was performed to identify existing best practices and emerging advanced techniques and solutions for decommissioning employed across the nuclear industry to meet the current and future needs. Moreover, a review of international initiatives (IAEA and NEA/OECD reports, EU projects, etc…) was carried out in relation to the thematic areas defined in the survey questionnaire.

Investigation of needs (issues, challenges, opportunities, etc.) was performed, followed by a gap analysis, taking into consideration needs, available solutions, and desired states, and by the identification of actions to fill the gaps.

In WP4, these proposed actions will then be organised by key topics in a Strategic Research Agenda (SRA), followed by a Roadmap for the next 10-15 years, with proposal of instruments for implementation.

Assessment of nuclear decommissioning technologies using GAP Analysis

Review of international best practices and advanced technologies

First step was to compare the stakeholder's needs with current available solutions or on-going initiatives and to implement an elaborated review of international best practices and advanced technologies in relation to the thematic areas defined in the survey questionnaire. This work was implemented by the consortium members and then confronted to feedback and additional inputs from a wider community of stakeholders during a public workshop in October 2020[6].

Dedicated workshop to prepare for the Gap analysis

Another workshop was organised in December 2020, to get stakeholders' valuable opinion on the choice of the 71 sub-thematic areas made by the consortium and to further investigate the needs for Research in each of the sub-thematic areas, in addition to the information on needs coming from the survey.

Stakeholders were first asked to give their opinion on remaining issues and challenges or on Research opportunities in decommissioning and legacy waste management.

This workshop was also a chance for sharing status and results of on-going developments with major international organisations.

A comprehensive community of 317 members of different stakeholders' type registered for this workshop (see distribution in Figure 2)[7].

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

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

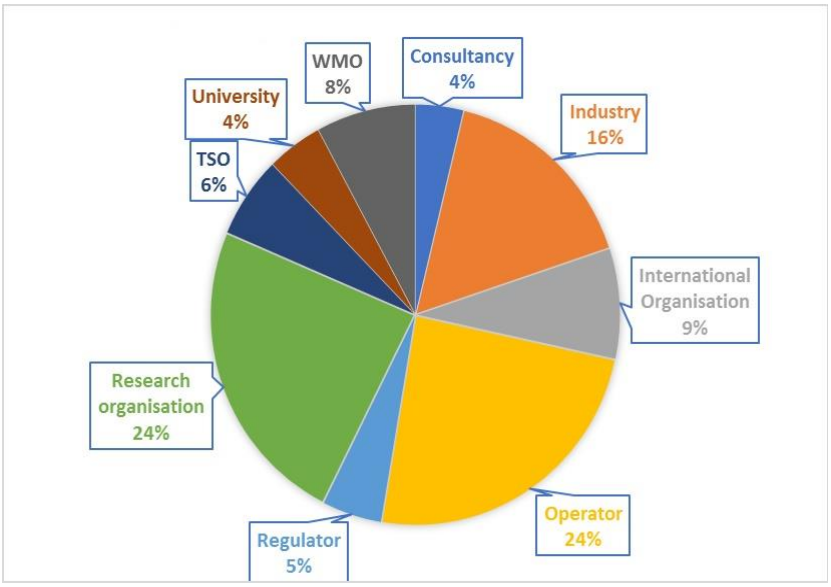

Figure 2: Distribution of registered participants by Stakeholder's type for December 2020 Workshop

To allow stakeholder community from all over the world to give input, virtual brainstorming post-it sessions were performed by the SHARE consortium team together with the workshop participants. The methodology followed during these break-out sessions is shown in Figure 3.

Figure 3: Methodology during break-out sessions

The 71 different break-out sessions were organised according to sub-thematic areas, with a variety of stakeholders participating depending on their topics of interest. Every breakout session was divided into different steps. Stakeholders raised various subjects which highlighted the technical and non-technical issues associated with decommissioning procedures. In the first step, stakeholders pointed out numerous needs in research for a particular sub-thematic area. These identified needs were grouped by the session chairs after discussion with the participants accordingly in the next step (step 2). For step 3, participants of each breakout session provided insights on current state of available solutions and opportunities against identified needs of step 1. This approach also helped stakeholders to conclude some first gaps in technology or methodology. This stepwise procedure shown in Figure 3 in different breakout sessions highlighted experience sharing, advancements in technologies, and best practices among the different organisation involved in decommissioning. One example of a virtual brainstorming whiteboard used for the December 2020 workshop for post-it breakout sessions is shown in Figure 4.

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

The collected data during the workshop was compiled together by the consortium partners in order to further perform the formal gap analysis.

Gap analysis

Gap analysis was carried out comparing remaining Research needs identified through the questionnaire and the different workshops with the status of existing solutions or ongoing initiatives.

This process focused on gaps in technology/ work practices and proposed for each sub-thematic area, a list of actions to fill the gap: research, development, guidance, demonstration of innovative solution, coordination with other entities, etc.

In this regard, all the detailed literature on existing best practices and emerging advanced techniques and solutions gathered, open questions from the survey, and opinions collected during December 2020 workshop were introduced in a tabulated form to undergo this gap analysis. A structured method considering issues, possible available solutions, and desired state helped to identify certain actions that can be further prioritised to become a part of SRA and Roadmap. The template of the table used for gap analysis is shown in Table 2.

Furthermore, Table 3 shows an overview where reoccurring needs from every thematic area are highlighted with results of gap analysis. This Table 3just provides some of the prominent results of the gap analysis in terms of proposed actions. The detailed results highlighting needs, proposed actions, and classification into different action types can be assessed on the projects' official website[8] in the form of a deliverable D3.2 'Technology assessment/ gap analysis report'.

[8] https://share-h2020.eu/project-deliverables/

Table 2: Excel table highlighting the methodology for gap analysis

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

Table 3: Result of gap analysis for reoccurring needs in different thematic areas

Needs or opportunities	Actions proposed		Type of action
Thematic area Q1 'Safety and radiological protection'			
International standardisation for safety requirements	Actions to enhance international harmonisation	of WAC, national regulatory requirements, and clearance criteria.	Networking
Emphasis on Good Practices and Procedures for radiological protection.	Benchmarking and guidance	to adopt best practices in decom procedures to uphold safety protocols	Guidance
Training and education on RP and digitalisation	Guidance and Development	to enhance the use of digital tools/develop scenarios	Development
New technologies to improve safety, reduce time and enhance stakeholder engagement	Actions to encourage future collaboration and coordination of Research and Innovation (R&I) activities	to improve acceptability of new technologies by stakeholders	Development
Thematic area Q2 'Project management and costs'			
Interoperability of all software used in decommissioning from Strategy and scenario	Development	to enhance interoperability between IT tools	Development

analysis to monitoring on site			
Data and information management	Enhance use of	BIM tools, Virtual training, risk management, VR, 3D modelling, and digitisation for decommissioning tasks	Development
Information and tools for communication	Development	communication tools to explain what is decommissioning (when site visits, etc.)	Development
Better costing tools for decommissioning	Coordination	with NEA and IAEA on dissemination of ISDC hierarchical structure among decommissioning projects	Dissemination
Thematic Area Q3 'Human resources and management'			
Inter and intra-organisation decommissioning mission and engagement between actors	Coordination between EU, IAEA and NEA to check if need to update existing documents and to disseminate information	on inter-organisational best practices for engagement between actors and to achieve more efficient organisation	Guidance
Knowledge capturing & sharing forms/formats (text, video, audio, etc.)	Actions to 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	Guidance
Secure young workforce: Attract & Motivate	Actions related to Education and training	to secure, attract, and motivate young workforce in D&D	Development
Standards & Regulations for task specific training methods & tools	Actions to enhance use of	immersive training methods & tools (through recognition, standards, certifications, etc.)	Development
Thematic Area Q4 'Characterisation during decommissioning'			
Difficulties to measure alpha and beta radionuclides (in situ, ex situ)	Development	on methodologies and technologies for DTM including automation (R&D and I&T)	Development
Fast, cheap, and straightforward methods for sample analysis	Development	for improvements of existing technologies	Development
Modelling and calculation methods	Guidance	on enhance and improve the use of models	Development

Automation in segregation of waste	Development	towards innovation of autonomous systems for segregation and handling	Development
Characterisation for segregation including legacy waste	Development	on technology of mobile systems to characterise containerised RW	Development
Thematic Area Q5 'Site preparatory activities'			
All identified needs were discussed in other thematic areas			
Thematic Area Q6 'Dismantling technologies'			
Segmentation strategy optimisation	Guidance	for the selection of segmentation strategy for metallic and concreate components	Guidance
Innovative remote autonomous techniques	Development	to integrate remote control dismantling techniques with 3D models and simulations	Development
Innovative cutting techniques	Development	of technologies and methodologies	Development
Modular and mobile solutions	Enhance use of	multi-purpose modular and mobile systems for different dismantling tasks	Development
Robotic solutions for specific circumstances	Development	on technologies and methodologies for hard to access areas with betterment in tele-operated remote arms	Development
Efficient Decontamination techniques	Benchmarking	for technologies and methodologies for in-situ decontamination with good rate and minimised secondary waste production	Guidance
Thematic Area Q7 'Environmental remediation and site release'			
Improvements in accuracy of predictive modelling	Development	of digital tools to facilitate the predictive modelling for contaminant transport, radionuclide behaviour in longer term and underground contamination	Development
Improvements in the capabilities of the soil remediation technologies	Development	to improve the practical implementation reducing time and costs	Development
Improvements in methodologies and techniques for final release survey of the Site	Dissemination	of experience exchange among the stakeholders to get greater harmonisation of processes	Guidance

Improvement in tools for statistical analysis and management of survey data for site release	Benchmarking and guidance	of existing IT tools available for statistical analysis and management of survey data for site release	Guidance
Thematic Area Q8 'Radioactive waste management'			
Waste minimisation opportunities	Actions to enhance	waste minimisation and optimisation during dismantling operations	Development
International harmonisation on management of waste transportation, standardisation and packaging	Actions to enhance harmonisation	of practices in packaging (transport, storage, disposal) management (metal, concrete , etc.) regarding clearance and acceptance criteria	Networking
Industrial implementation of emerging technologies for waste treatment	Actions to encourage use of new developments	to better manage waste flows from production to disposal (IT tools and other emerging technologies)	Development
Simplify the handling of secondary waste from processing	Developments	to simplify the handling of secondary waste from decontamination, fusion or other processing for metallic waste from decommissioning	Development
Management of small volumes of diverse wastes	State of the art and Guidance	on use of mobile devices for treatment of liquid effluents	Development
Optimise packaging solution (from decom, transportation, storage to disposal)	Guidance and enhance harmonisation of practices	through coordination between Waste producers and WMO's to provide on best strategy for packaging	Guidance
Solutions for Reconditioning of historical waste already conditioned	Benchmarking, Development and Guidance	on legacy/ historical waste management	Guidance
Enhance recycling of released materials	Actions to enhance	recycling of metal (in and out of nuclear sector)	Development
Public acceptance on recycled or clean waste from radioactive sites	Actions related to societal issues/dialogues	for acceptance of reuse of material	Networking

Some of the needs or opportunities are quite specific for one thematic area (e.g. different levels of radioactive waste management, characterisation of DTM radionuclides, specific dismantling tasks etc.) others are appearing, with varying emphasis, in different thematic areas, e.g. education & training, knowledge management, improving of technologies, international harmonisation on RP and standards etc. These has to be taken into account for the final goal, the roadmap and the SRA.

Proposed actions

In order to keep the stakeholder involved, the outcomes of this gap analysis of each sub-thematic area were presented in terms of proposed actions that have an impact on the needs identified through survey questionnaire and workshops. A wider stakeholder community registered for the SHARE sessions detained during DigiDECOM 2021 conference. The participants of this workshop approved proposed actions and also provided valuable feedback on some missing actions[9]. These actions will then be organised by key research topic in the future Strategic Research Agenda (SRA) and the corresponding SHARE roadmap. The proposed actions from table 3 were structured into 4 major types of actions to provide a better overview;

Development: actions of R&D, D&D, innovation. This includes preliminary actions like “state of the art”, benchmarking or later actions related to industrialisation, commercialisation, and actions to enhance use of the developed product.

Networking: actions to encourage future collaboration and coordination, actions to influence harmonisation of practices, and actions to influence change of practice: e.g. to organise future working groups or platforms, to adapt regulation, legislation, etc.

Guidance: actions to homogenise and elaborate counselling documents to provide advices on best practices in technical and non-technical domains, methodologies, standards, etc.

Dissemination: public information through different channels: e.g. conferences, workshops, Education and Training, Knowledge Management, IT tools, etc.

The Table 4 summarises the extensive division of different proposed actions on identified needs coming through gap analysis, in 4 major types of actions. ‘+++’ denotes greater number of proposed actions toward particular type of action. Similarly, ‘++’ and ‘+’ shows decreasing intensity for particular action. Blank space highlights that no particular need was identified that would have impact by certain type of action.

Table 4: Summary of gap analysis in terms of proposed action types on identified research needs

Thematic areas	Type of actions			
	Development	Networking	Guidance	Dissemination
Safety and radiological protection aspects	++	+++	+	+
Project management and costing	+++	+	+++	+
Human resources management	+++	+	+++	
Characterisation during decommissioning	+++		++	+
Site preparatory activities	++		++	+
Dismantling technologies	+++		+++	
Environmental remediation and site release	++	+	++	
Management of material and radioactive waste from decommissioning	+++	+++	+++	

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

The descriptive list coming from gap analysis that provides actions specific to the identified needs for all 71 sub-thematic areas can be accessed on the projects' official website[10] in the form of a deliverable D3.2 'Technology assessment/ gap analysis report'. The global representation of division of 71 sub-thematic areas in different action types can be seen in Figure 5.

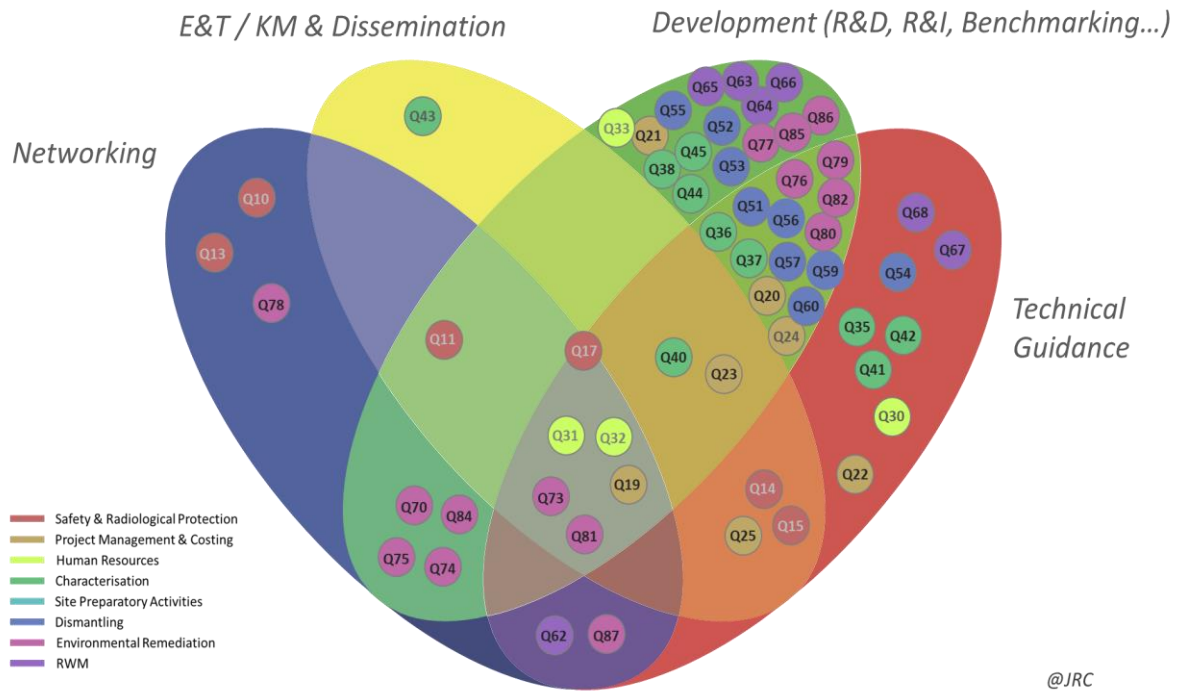

Figure 5: Overall distribution of the 71 sub-thematic areas in 4 main types of actions

Conclusion

In the scope of the SHARE project, the "Gap analysis" task has highlighted different issues related to research, education, innovation, and regulation that can support the assessment and comparison of technologies to enlighten the development of an action plan. In addition, the results obtained in the analysis has not only highlighted technical concerns but also some issues related to standardisation, safety, education and training, knowledge management, and dissemination. The compiled actions through gap analysis will be further grouped and introduced as key research topics for future SRA and Roadmap for research in decommissioning.

Note of Thanks

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[10] https://share-h2020.eu/project-deliverables/