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Gap Analysis
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Abstract

A Gap Analysis was conducted in two separate phases: 1) to evaluate industry and stakeholder needs for research, development and demonstration in predisposal waste management technologies and initially define the scope of the PREDIS project and 2) to further review, refine and prioritise project plans against identified needs and discern additional needs. Information was gathered by a variety of methods, including quantitative and qualitative surveys, live polling, interviews with end-users, webinar presentations, discussion groups and literature reviews. While a strong and important feedback cycle from industry end user group members representing waste generators, waste owners and waste management organisations was already implemented during the project preparation (gap analysis phase 1), this outreach was significantly strengthened and intensified after the launch of PREDIS to collect additional feedback on the project direction (gap analysis phase 2).

This report summarises the combined findings of both phases of the gap analysis work which were conducted during the 2019 proposal preparation period and, in more in-depth fashion, during the first eight months of the project (September 2020 through April 2021). The phase 1 results influenced how the scope of the project was selected. The phase 2 results further refined the project scope and evaluated and prioritised additional topical gaps. The phase 2 outcomes are presented specific to the technical work packages of the PREDIS project representing metallic waste streams, liquid organic and solid organic waste streams and the monitoring and storage of cemented waste packages.

Of the gaps identified on the basis of the defined objectives and processes, most (58 %) are already in the scope of the PREDIS technical work packages and only 10% were well outside the scope of PREDIS. Another portion of topics can be considered for inclusion by modification of the existing work package tasks. More specifically (relative to the scope of the PREDIS project), the findings of phase 2 showed:

- 77 gap identified topics/issues were already in-scope (of the PREDIS project),
- 14 gap identified topics/issues were not in-scope, but could be (relevant to the PREDIS project),
- 34 gap identified topics/issues were not in-scope and cannot be, but could be promoted to the SRA,
- 7 gap identified topics/issues were not in-scope and should not be (considered further in PREDIS).

It can be concluded that the project was originally well-designed based on the steps taken during the background preparation phase. The outcomes of the phase 2 gap analysis work will be used to refine the scope of work for the various technical work packages. These refinements will be described in the modified Description of Action after the year one periodic review. The results of the phase 1 gap analysis work provide clear justifications and transparency for the selection of the four technical work packages and their tasks. Some topics that arose during the Gap Analysis that are determined to be outside the scope of the PREDIS project will be considered for integration to the Strategic Research Agenda as a future public deliverable of PREDIS and others are completely out of scope.

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18.5.2021	0.1	Schatz, Holt	Initial Draft, for external comments
20.5.2021	0.2	Schatz, Holt	Input WP summaries to Ch 6 (earlier hold for Appendices)
25.5.2021	0.3	many	Editorial comments from partners
29.5.2021	0.4	Schatz, Holt	Address of comments (v2.0), to partners for final check
31.5.2021	1.0	Schatz, Holt	Final report, for EC submission. PREDIS publication (webpage)

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1 Preface

The PREDIS (Predisposal Management of Radioactive Waste) project has conducted a two-phase Gap Analysis to 1) identify industry needs for research, development and demonstration (RD&D) and initially define the scope of the project and 2) to further review, refine and prioritise project plans against identified needs and discern additional needs . Initial work was performed during the project preparation phase to define the scope of work topics of most interest to the end user community, and then further continued during the first eight months of the project (September 2020 to April 2021) to provide more input on the detailed work programme, based on the European Commission (EC) request. A variety of methods were used to collect feedback from industry as well as members of the wider stakeholder community and consortium partners. The leaders of PREDIS RD&D work packages 4-7 have provided analysis and contributed summaries for their respective technology areas.

This report was available for all partners to review and provide feedback prior to publication. The report was internally peer-reviewed by two members of the project consortium, Anthony Banford (NNL, UK; WP leader) and Christophe Bruggeman (SCK CEN, Belgium) and also externally peer-reviewed by two reviewers: 1) Piet Zuidema, (Zuidema Consult GmbH, Switzerland), and 2) Tara Beattie, (TB Environmental Services, UK). Outcomes from the Gap Analysis work can be used to refine the scope of the PREDIS work programme, if necessary, within the technical work packages 4-7 on the material waste stream processing or can be ear-marked for potential future activities. These refinements will be described in the modified Description of Action after the year one periodic review (autumn 2021) and are outside the scope of this deliverable. Many items of the Gap Analysis will also be considered for integration in the Strategic Research Agenda as a future public deliverable of PREDIS.

2 Introduction

The aim of this document is to provide a description of the framework, methodology and results for the PREDIS project Gap Analysis. This work was conducted both during proposal preparation to define the original scope of the project and then within Task 2.6 during the first eight months of the project to evaluate if the project is focused on the highest priority technology development needs of industry across many Member States, and to provide clearer justifications and transparency for the four selected technical work packages and their tasks. The later phase of the Gap Analysis was carried out to further refine the technical work packages based on end user feedback, especially with regard to the focus and potential effort weighting between the tasks.

The PREDIS proposal was planned and submitted to the Euratom call NFRP-10 for research and innovation in 2019. The four-year project targets the development and improvement of activities for the characterisation, processing, storage and acceptance of intermediate- and low-level (ILW/LLW) radioactive waste streams. The focus is on the treatment and conditioning of metallic materials, liquid organic wastes and solid organic wastes arising from nuclear plant operations, decommissioning and other industrial processes. The project also addresses monitoring and digitalisation[1] solutions for improvements in handling and assessing cemented-waste packages in extended interim surface storage.

The preparations for the PREDIS project proposal were made primarily from within the Implementing Geological Disposal and Nugenia or Sustainable Nuclear Energy Technology Platforms (IGD-TP and SNETP, respectively), and in close synergy with the European Joint Program on Radioactive Waste management (EURAD). Background information from the JOPRAD project (2015-17) was also taken into account. The project scope was developed with strong industry feedback regarding priority needs targeting specific waste streams, with tasks aligned to innovations in treatment and conditioning of liquid organic, solid organic and metallic wastes and storage of cemented wastes.

As the project was to be in-line with the joint-funding concept of research activities (Work packages 4 to 7) receive only 50% funding of the direct costs, and thus it is important that the focus of the project also be tailored to the needs of the co-financing organisations (such as industry Nuclear Power Plant operators and waste

[1] Enabling or improving processes by leveraging digital technologies and digitised data.

generators). The project budget is 23.7 M€ total, of which 14 M€ is provided by the EC and 9.7 M€ obtained by national level co-financing arranged by partners. Importantly, 80% of the project budget is devoted to research, development and demonstration (RD&D) activities.

The European Commission's PREDIS proposal evaluation noted the following three issues pertaining to the Gap Analysis expectations that they recommended PREDIS to address within the project scope:

- "*The process and basis to arrive at the selection of topics to be included is, however, not apparent from the proposal.*
- *The methodology of the individual work packages is well developed, sound and credible. However, the structure behind the selection and how the selection has been made is not described. Each component certainly has good reasons for being selected but it is not clear how the priority has been made and what tasks have been given a lower priority*
- *"As proposed, all activities start at day 1 and there is no mechanism for adapting the work packages to the outcome of the strategic considerations."*

To address these comments, the PREDIS project implemented the Gap Analysis activities (as Task 2.6, led by VTT Technical Research Centre of Finland). The objectives of the Gap Analysis are firstly, to clarify why the consortium selected the project's technical topics and secondly, to evaluate if something in the scope should be adjusted (including weighting of scope between WPs and/or tasks). This Gap Analysis process activated in the first phase of the project has also allowed a wide community to give feedback on the technology development needs and priorities. All 47 consortium members as well as a large and varied stakeholder community have contributed to the Gap Analysis via multiple activities, which are described in this report. Based on the Gap Analysis outcomes presented here, adjustments will be made to the projects Description of Action at Milestone 3 (Month 18) after the first periodic review at Month 12 (September 2021). Figure 1 below indicates the historic, current and future information that is linked to the PREDIS Gap Analysis activities. It aims at illustrating the harmony and sequence, which is also reflected in this report format.

This report is structured to provide clarity about the gap analysis objectives (Chapter 3), followed by a more detailed description about how the initial work scope (Work packages and Tasks) was originally selected in the first portion of the gap analysis work (Chapter 4). This information was not detailed in the original proposal due to document file size limitations, but it does provide important insights about how topics for the project were selected. The next section (Chapter 5) describes the Methodologies used to gather information for the Gap Analysis. The Results and Main Findings (Chapter 6) cover the key outcomes, arranged per Work package and then an overall evaluation for the predisposal waste management domain. The final Summary (Chapter 7) provides the general assessment after completing the Gap Analysis and addresses how the findings will be utilised.

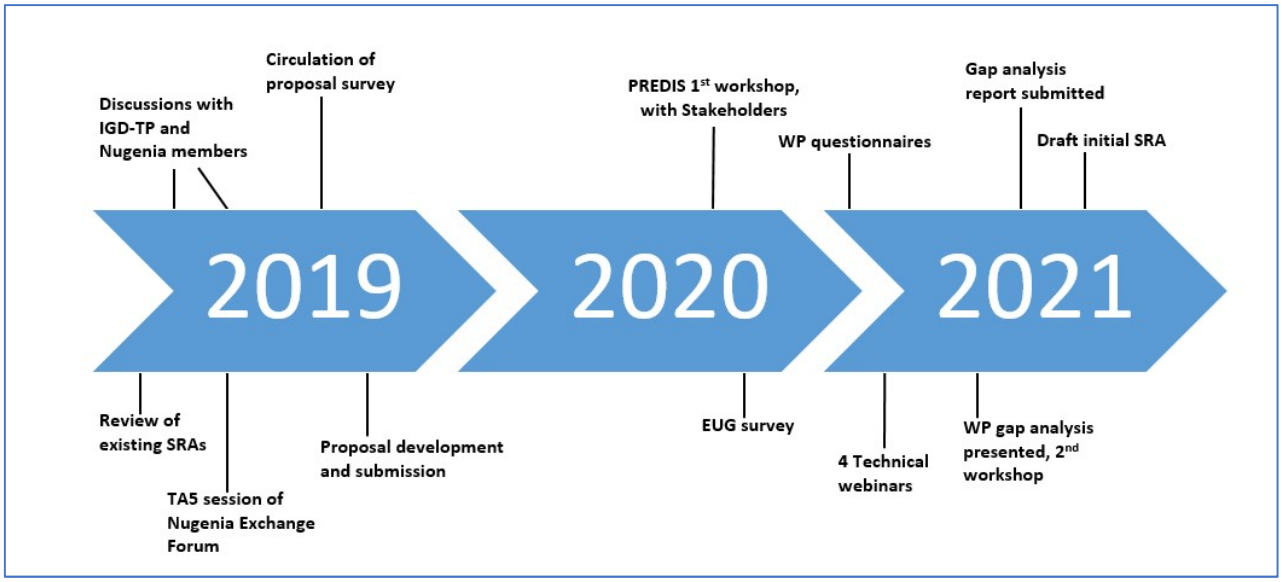


Figure 1. Timeline of the PREDIS Gap Analysis activities.

3 Gap Analysis Objectives

The RD&D needs for predisposal waste management span a wide range of activities, from waste generation through to final disposal. There is also overlap and necessary RD&D synergies with decommissioning and disposability issues, for instance on topics of waste classification, waste acceptance criteria and packaging. This overlapping range of activities is illustrated in Figure 2, showing how the scope of PREDIS is complimentary to the SHARE and EURAD projects. It must be noted that the EURAD and SHARE projects also touch on predisposal waste management issues, and there are also some gaps and overlaps such as EURAD covering high-level waste and spent fuel before disposal. It is acceptable that there may be several projects tackling sometimes similar topics, but they all fit together within this “cradle to grave” view of waste management. The interfaces between the three projects of PREDIS, SHARE and EURAD are very important, also during the gap analysis and Strategic Research Agenda developments.

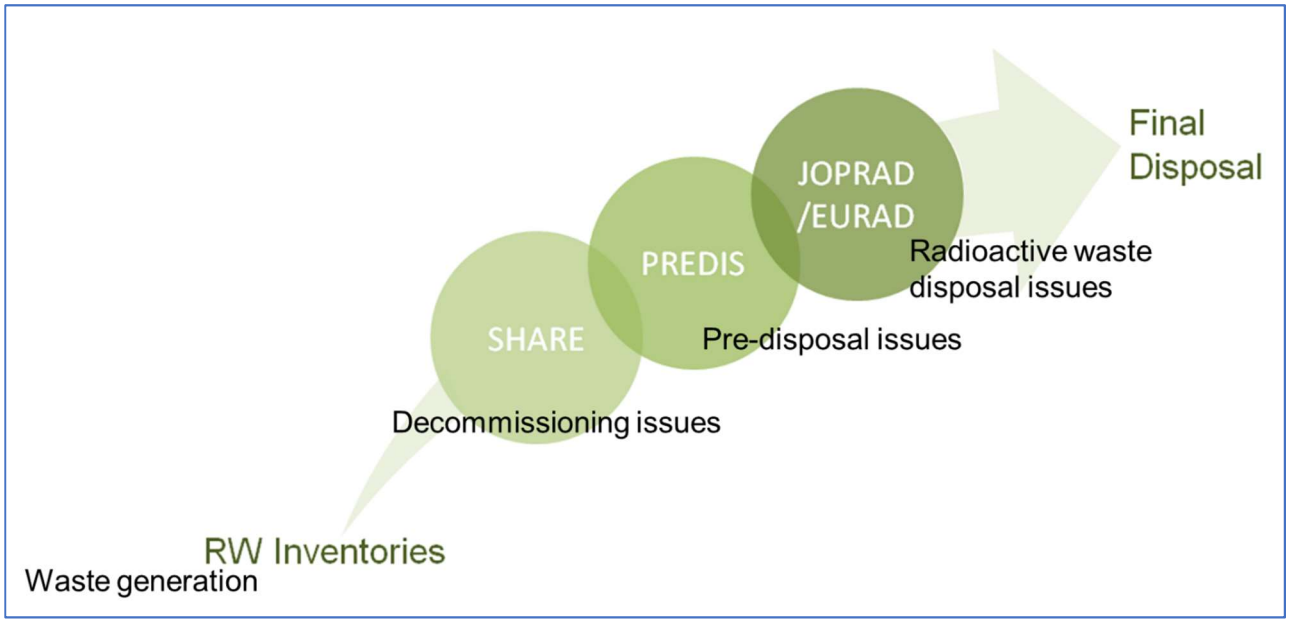


Figure 2. PREDIS project interfaces with upstream and downstream domains.

The Gap Analysis in the PREDIS proposal preparation phase (Phase 1) and also during the first eight months of the project implementation (Phase 2) was focused on **research and technology** gaps in the predisposal management of radioactive wastes. Efforts were primarily aimed at identifying those gaps to which the PREDIS project itself could directly contribute. Specifically, gaps of interest are those meeting the following criteria:

- represent areas of clear need by many Member States (e.g., problematic wastes, wastes with large and/or increasing raw volumes),
- represent opportunities for effective and immediate investment return (0- to 4-year horizon with an expectation of a jump in technology readiness (maturation) within that timeframe),
- represent topics of importance to industry, with a commitment to implement (co-funding potential),
- identified in Strategic Research Agendas of the community (i.e., EURAD, IGD-TP, SNETP/Nugenia).

Conversely, another set of constraints were applied to rule out some types of gaps. In particular, excluded gaps are those falling under the following areas:

- represent specific decommissioning-related, disposal-related, high-level waste (spent fuel)-related technology RD&D topics sufficiently addressed elsewhere and outside the scope of the Euratom call (covered, e.g., by the EURAD and SHARE projects),
- represent networking or coordinated action topics, for instance as handled by IAEA and OECD-NEA,
- represent areas of limited need (few interested parties or Member State applicability).

It has always been recognised that additional RD&D topics may be raised during the Gap Analysis that do not fit the scope of the PREDIS project technical work packages but are still very relevant to the community. Such topics can then be addressed by the predisposal radioactive waste management Strategic Research Agenda (SRA) developed in PREDIS within Task 2.2, led by the National Nuclear Laboratory (UK) which is to produce a draft compilation SRA in September 2021 (confidential) and then the final public SRA of PREDIS as Deliverable D2.3 ready in summer 2024.

The Phase 1 Gap Analysis was during proposal development (Chapter 4) and the Phase 2 Gap Analysis activities (Chapter 5) of Work package 2, Task 2.6 during the initiation period of the project were targeted towards assessing in detail the technical topics of PREDIS that form the basis of Work packages 4 to 7. Both of these phases are described in the next chapters, followed by the analysis.

4 Phase 1 Gap Analysis

The PREDIS project targets innovative and break-through technologies for safer, more efficient, economic, and environmentally friendly handling of low and intermediate level waste (LILW) for all Member States. When originally preparing the project proposal, a gap analysis was carried out in spring 2019 through both literature reviews and discussions with industry.

As seen earlier in Figure 1, the first background activity was to review existing Strategic Research Agendas (SRA) to consider what had already been flagged as important needs. Three SRAs were identified in the proposal: the Nugenia Global Vision (2015) associated with Technical Area 5 in radwaste and decommissioning, the JOPRAD Programme Document (Deliverable 4.2, 2018), and the EURAD project founding documents (2019).

For instance, the EURAD SRA Theme 2 on “Radioactive Waste Characterisation, Processing and Storage (pre-disposal activities) and Source Term Understanding for Disposal” clearly identified the following relevant high and medium priority topics that were directly relevant to the PREDIS proposal: High priority: Developing novel conditioning technologies for non-mature and problematic waste (relevant to WP4-6)

- High priority: Improved understanding of radionuclide release from existing and future wasteforms other than Spent Fuel (relevant to WP5-6)
- High priority: Improved understanding of the impacts of extended storage on waste package performance. (relevant to WP7)
- Medium: Optimisation of radioactive waste treatment techniques where there is potential for volume/hazard reduction and potential cost savings (relevant to WP4-6)
- Medium priority: Demonstration of geopolymer performance in representative disposal conditions. (relevant to WP5-6)
- Medium priority: Developing reliable and affordable technologies for the radiological characterization and segregation of historical preconditioned radioactive waste (including non-destructive assay techniques to provide quality assurance of packages being stored; relevant to WP7).

From the Nugenia Global Vision, Chapter 6.2 (Technical Area 5B) related to waste management noted the overarching challenges to address, and those which were considered in the PREDIS proposal included:

- To innovate enhanced decontamination and dismantling technologies for structures and components, (relevant to WP4)
- To establish improved treatment technologies (thermal or other) to reuse/recycle materials, minimise waste volumes and to develop robust and passive waste forms (relevant to WP4-6)
- Optimisation of wastes treatment by investigating alternative or novel wasteform matrices and their associated processing routes. Such methods may include alternative cementation or other ambient temperature processing routes. (relevant to WP4-6)
- To accelerate the introduction of new technologies and technical approaches through inactive and active demonstrations (relevant to WP4-7)
- Waste minimisation strategies for decommissioning, incl. safe release of material to the environment, recycle/reuse, disposal to VLLW repositories (relevant to WP4-6)

- Tools for surveillance programmes and active condition monitoring during interim storage; also improved in-situ monitoring technologies, risk-based approaches to decision making (relevant to WP7)

In terms of industry feedback for the gap analysis, verbal discussions, presentations and surveys were made with members of the IGD-TP and Nugenia (now SNETP). Industry end users associated with EURAD are represented by IGD-TP. Inquiries were targeted to those companies responsible for waste predisposal activities, such as Nuclear Power Plant (NPP) and research reactor operators as waste generators, as well as organisations offering solutions for waste processing. It was also important to understand and account for the concerns of the waste management organisations who need to implement final disposal of the waste streams after processing. As the project scope was defined by the Euratom call on low- and intermediate-level radioactive waste (LILW), legacy wastes and waste streams from other industrial sectors beyond just power generation were included.

The IGD-TP provided a 3-page position paper on 12 March 2019 regarding the EC call NFRP-10, addressed to EURAD PMO and EURAD-Science networks. It clearly stated, “The first priority for the majority of the IGD-TP members are treatment and conditioning of organic wastes, comprised of liquid wastes and solid wastes (bitumen, ion-exchange resins, polymers).”

The Technical Area 5 session of the Nugenia (now SNETP) Exchange Forum in France on 15 March 2019 was organised to collect feedback on challenges for both predisposal radioactive waste management and decommissioning. An open solicitation was made to the community to suggest topics beforehand by submitting short abstracts. Regarding waste management, 21 abstracts and 19 pitching presentations were given by 14 organisations to present potential RD&D collaboration topics. Approximately 50 persons attended the session, representing 35 organisations, with the event agenda listing presentation topics shown in Appendix 1. The EC officer related to waste management also presented in the plenary session regarding the EC expectations for the Euratom call.

After the SNETP event, the presented topics were grouped into six themes, with written summaries distributed to industry stakeholders of the IGD-TP and SNETP communities to provide feedback on their priority needs. This feedback was requested in the form of a survey, as shown in Appendix 2, and was carried out via email and 14 replies were received, including the combined feedback from IGD-TP. Participants were asked to specify, “Which waste types [liquid organic, solid organic,[2] metallic,[3] graphite and cemented] are relevant for your organisations?” and “Which waste type [of those specified in the answer to the previous question] should receive highest priority?” on a scale from 1 (“high”) to 6 (“low”).

Figure 3 shows the mean priority ranking given to the five waste types with scoring from 6 to 1 (where 6 = highest, 5 = high, 4 = medium, 3 = low, 2 = lowest and 1 = not a priority) for respondent assigned values from 1 to 6, respectively. It can be seen that the waste types prioritised as most important were solid organic (mean = 4.85) and cemented (mean = 4.83) wastes. Graphite waste were given the least important rating in terms of priority (mean = 3.56). Furthermore, comments received for graphite indicated that the development of treatment and conditioning methods for graphite materials could be postponed into future research activities:

- “A large volume waste but the lowest priority for us.”
- “Large volume of graphite will be removed from reactors and packaged for interim storage as LL wastes.”
- “Lowest priority linked also to the long time-scale connected to the benefit from the outcome.”

Based on received comments, it could be also concluded that qualification and acceptance of waste was seen as important but could be included into the work plan as an incorporated aspect, and not necessarily as a separate work package. Another reason for including WAC issues into Work Package 2 as a strategic study rather than technical RD&D topic in the project was the predicted difficulty in getting co-financing for such work.

[2] Further subcategorised into bituminised waste, polymerised waste, resins, consumables and others.
[3] Further subcategorised into reactive metals, contaminated steel, activated steel and others.

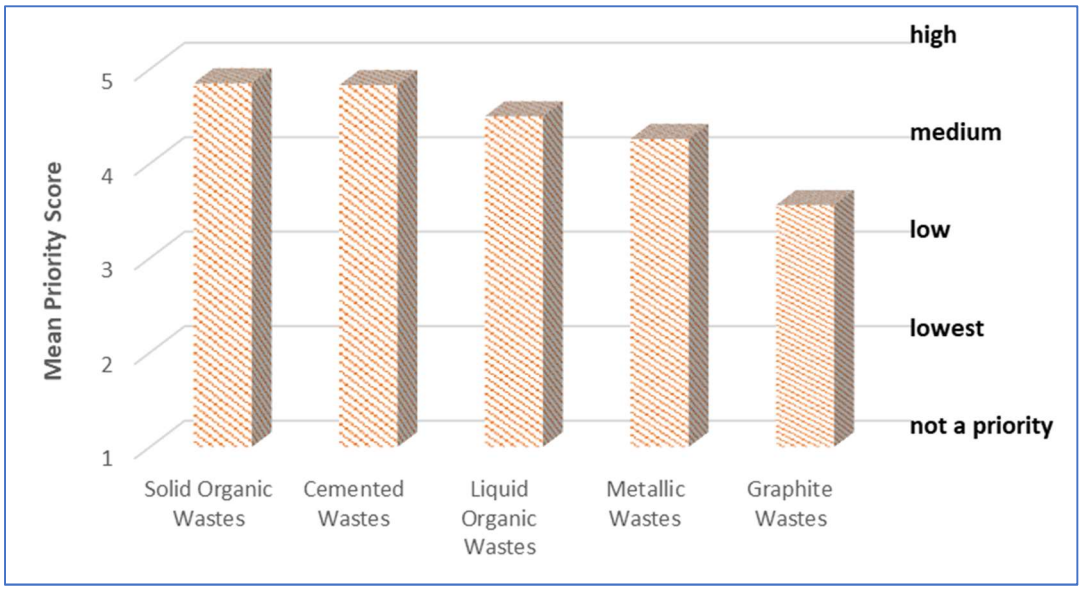


Figure 3. Mean priority scores for waste types from the pre-project survey *(6 = highest, 1 = not a priority).*

Additionally, in the industry pre-proposal survey, participants were also asked to provide their assessments of a set of six proposed work packages (i.e., work package 1: treatment and recycling of metallic materials and waste, work package 2: graphite materials treatment and conditioning, work package 3: liquid organic waste, work package 4: solid organic waste, work package 5: cemented waste and packages and work package 6: qualification and acceptance of waste) with respect to:

- "The clarity, pertinence and outlook on the achievability of the stated objectives (based on your insights) of the WP;"
- "The innovative character of the work proposed, and if the WP would contribute sufficiently to the increase of scientific and technical knowledge (beyond state of the art);"
- "The relevance of the end results for your organisation, the share of your inventory that can benefit from the WP results, and the added value that is created by the WP;"
- "An estimation at what point in the future do you hope to gain benefit from the outcome of the WP and how;"
- "Other needs you think are missing if any."

Examples of responses from the WMOs or waste generator/owners are shown below with regard to 1) clarity of the plans, 2) innovation aspect, 3) relevance of technology development for the specific waste type, and 4) expected timeline seen for the development needs. The examples are given in Tables 1, 2 and 3 for three of the six proposed work packages regarding the liquid organics waste treatment and conditioning, graphite materials treatment and conditioning, and qualification and acceptance of waste.

Table 1. Responses from WMOs regarding aspects of proposed liquid organic waste package.

Liquid organics	Clarity	Innovation	Relevance	Time/Outcome
WMO/owner 1	Yes	Yes	Yes	Yes
WMO/owner 2	Yes	Yes	Yes	
WMO/owner 3	-	-	-	-
WMO/owner 4		Yes	Yes	
WMO/owner 5	Yes	Yes	Yes	Long-Term
WMO/owner 6		Yes	Yes	
WMO/owner 7	Yes	Maybe	No	Maybe
WMO/owner 8	-	-	-	-
WMO/owner 9	-	-	-	-

Table 2. Responses from WMOs regarding aspects of proposed graphite waste package.

Graphite	Clarity	Innovation	Relevance	Time/Outcome
WMO/owner 1	Yes	Maybe	Maybe	Long-Term
WMO/owner 2	-	-	No	
WMO/owner 3	-	-	-	-
WMO/owner 4	-	-	Yes	
WMO/owner 5	Yes	No	Maybe	Maybe
WMO/owner 6	-	-	-	-
WMO/owner 7	Yes	Yes	Yes	Yes
WMO/owner 8	-	-	-	-
WMO/owner 9	-	-	-	-

Table 3. Responses from WMOs regarding aspects of proposed qualification and waste acceptance package.

Qualification & Waste Acceptance issues	Clarity	Innovation	Relevance	Time/Outcome
WMO/owner 1	-	-	-	-
WMO/owner 2	Maybe	Maybe	Maybe	Maybe
WMO/owner 3			Yes	
WMO/owner 4		Yes	Yes	
WMO/owner 5	Maybe	Maybe	Maybe	
WMO/owner 6		Yes	Yes	
WMO/owner 7	Yes	Maybe	Yes	
WMO/owner 8	-	-	-	-
WMO/owner 9	-	-	-	-

Lastly, participants were asked in terms of their potential involvement in the project as End Users, to indicate their potential role in the project as a potential partner or just as an end-user following the project. The majority answered with their interest and commitment to follow the project as an end user.

Overall, the survey showed that the majority of parties supported the research work packages on cemented waste, liquid organic waste, solid organic waste, metallic waste and qualification and acceptance of waste. The survey also indicated that some topics could be left out of the proposal because either 1) the urgency was not high enough (within 10 years), 2) the necessary investment or budget to result in technical progress was too high (over 50 million euros), 3) the reach or applicability to a significant number of Member States was too low, 4) the overall industry interest was not significant enough (e.g., not warranting co-financing), or 5) a combination of these four factors. As such, the topics that were excluded from the proposal after the industry survey were issues related to uranium conditioning and graphite waste processing, while the topic of bitumen waste processing was left as optional (in work package 6). It is acknowledged that these topics should still be accommodated in the PREDIS Strategic Research Agenda.

Based on the survey results, it was decided to focus the proposal into four material waste streams, with the bulk of the effort to be put on treatment and conditioning technology activities. In order to effectively address such topics, it is also necessary to consider up-stream waste characterisation needs and downstream long-term performance concerns. Furthermore, to complete full assessments for implementation, end users need to understand the economic and environmental impact of the new technologies. A holistic approach to the proposal was then formed, as shown in Figure 4, with the Work Packages represented vertically (waste streams) and task areas horizontally (technology innovation actions). The technical scope of the work packages is summarised in Appendix 3, giving the tasks and innovation objectives for each. The project Management Team made a decision during proposal preparation to allocate roughly the same budget to each work package (~20% each of the total project budget), as the easiest way to avoid biases between topics since the importance and urgency is highly variable between national programs, industry needs and partner preferences. It was also deemed important that each work package had the scope (and programme) to make an advance in technology readiness level (TRL) during the course of the PREDIS project.

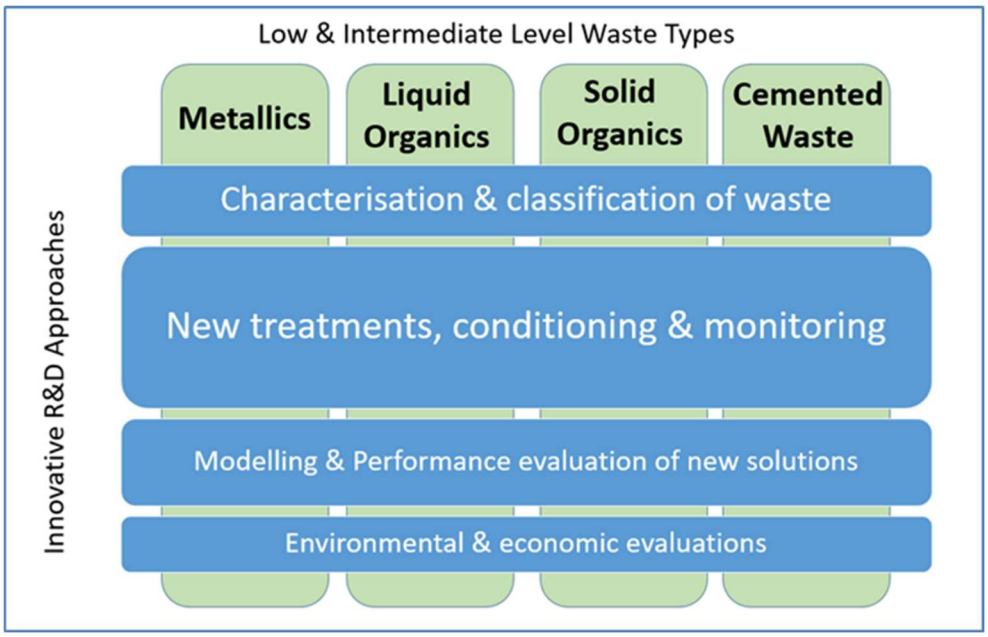


Figure 4. Structure of PREDIS project, based on industry feedback.

In July 2019, a presentation of the proposal content was circulated to the same industry group to solicit additional feedback on the proposal structure and content. The feedback received noted that the proposal was representative of industry views and no urgent or critical suggestions were given for improvements. Feedback was received from Ian Gordon of IAEA, 29 July 2019. The proposal was also reviewed in detail by the EURAD coordinator's Project Management Office led by Andra (France), with comments received 20 September 2019.

With regard to Nugenia (now part of SNETP), the NUGENIA Executive Committee provided the PREDIS proposal the NUGENIA label of endorsement in August 2019. Feedback and inquires to join the consortium from Nugenia members could be provided on the proposal summary published on the NUGENIA Open Innovation Platform during summer 2019.

Further holistic international insights and feedback were obtained by discussions with IAEA, OECD-NEA, the EURAD project management office as well as the EC officer, regarding their views of the current needs and challenges of the predisposal waste management community. These discussions were held at the EURADWASTE'19 Conference organised by the European Commission in June 2019 in Romania. This information built upon the initial discussions held among the community and with the EC Officer Christophe Davies after his presentation at the IGD-TP Exchange Forum held in Berlin, December 2018, and explained the progress made in proposal concept development during spring 2019.

All of the background actions during 2019, from reviewing existing documentation, soliciting feedback from industry, and engaging in discussions with large organisations representing various stakeholders, contributed to the formulation of the project proposal structure and content. Furthermore, solicitations to contribute to the proposal development were made available and openly to the whole community through the Nugenia, SITEX and EURAD Science networks. Additionally, the IGD-TP was invited several times during the process to provide feedback. These actions led to a very inclusive project proposal process, in line with the EURAD vision. These activities have been described in this section to record the extensive work and, open and transparent process that led to the PREDIS project proposal, which could not be included in the project proposal due to page limits.

The next sections describe the Gap Analysis objectives, methods and findings that were then performed after the official start of the project, from September 2020, through April 2021.

5 Phase 2 Gap Analysis Process

5.1 Gap Analysis Methodology

At a very general level, a gap analysis compares a current situation with a potential or desired state. It usually involves evaluating the following items: 1) areas of focus, 2) goals to achieve, 3) known current state, 4) desired target future state, and 5) actions towards bridging the gap between the two states. In the RD&D sense, a gap analysis helps target (identify goals) where a project should focus to generate greatest impact across several potential dimensions, including items that may be actor-specific and those having scientific, financial and/or societal impacts (Figure 5). In some cases, there may also be legal and political (policy) issues that may also factor into a gap analysis.

Actor-Specific impacts	Scientific impacts	Financial impacts	Societal impacts
•new products, services •improved performance •improved skills or competences	•quality of science & technology •innovation •organisational performance	•revenue, turnover •new solutions, increased offering •adequate funding sources available	•protection of citizens •protection of environment •economic renewal/growth

Figure 5. Areas of impact expected from a project or investment that may be accounted for in a gap analysis.

For PREDIS, one important focus of the Gap Analysis in both the proposal and project phase has been on assessing **scientific impacts** or the **technology** gaps which are evaluated with respect to their *Technology Readiness Level* (TRL). TRL is a common classification system, showing progress from basic research through laboratory programs to ultimately system readiness and wide acceptance (see Figure 6). PREDIS tasks should aim at improving TRL levels, especially at the higher levels closer to industry implementation. Initial TRL states and PREDIS outcome expectations per work package and task were described in the project proposal and will be elaborated on in future deliverable reports.

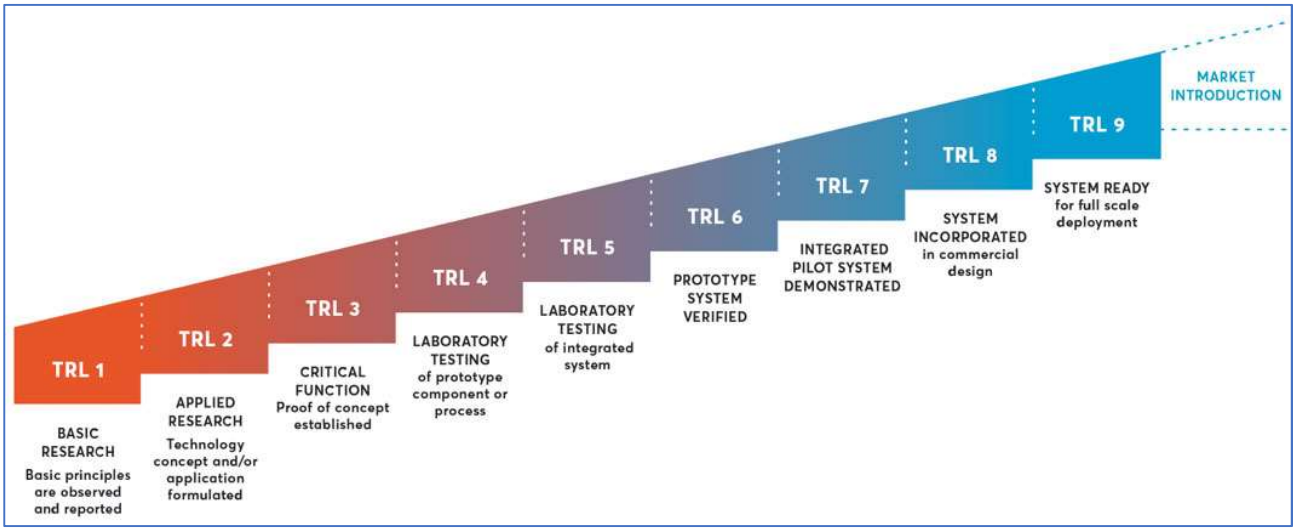


Figure 6. Technology Readiness Level (TRL) assessment scale[4].

Data collection for a gap analysis is accomplished using a variety of methods and targets as wide an audience as possible. Methods that can be utilised can include:

[4] *Image source:* https://climateinnovationwindow.eu/what-trl

- reviewing existing literature, such as strategic research agendas, position papers, current developments/projects already ongoing,
- reviewing past surveys, so as to not repeat previous efforts unless significant change is anticipated
- conducting technical state-of-the art reviews,
- creating and administering surveys, either:
    - quantitative with numeric rankings or prioritisations
    - qualitative open-answer free replies
- hosting workshops covering current practices, challenges and future needs:
    - presentations from industry,
    - discussion groups about prioritisation,
    - live polling of opinions (multiple choice and free form words),
- individual interviews or discussions with industry, to hear direct feedback.

5.2 PREDIS Industry Identification

Within PREDIS Work Package 2, Task 2.1 was focused, over the first six months of the project, on identifying relevant End User Group members comprised of companies that are either waste generators, waste owners or waste management (disposal) organisations. A wider community of stakeholders has also been identified, including regulators, technical support organisations, research organisations, universities, supply chain companies and civil society members. These groups have been invited to participate in some of the Phase 2 Gap Analysis events, especially the webinars which included live polling and discussion groups. The End User Group (EUG) of the project is continuously growing and is currently composed of 23 external members from 14 countries. More information is available in PREDIS Newsletter No. 2 published in April 2021 and on the PREDIS website at https://predis-h2020.eu/end-user-group/. There are an additional 15 PREDIS consortium members that are also considered EUG members due to their roles (for instance operating a research reactor and associated waste management facilities). An additional 67 potential EUG members and 119 stakeholders from 33 countries have been identified and have been contacted to solicit their involvement.

New members can apply to join the EUG or Stakeholders group directly from the PREDIS website (https://predis-h2020.eu/end-user-group/) throughout the project. The EUG has been a key source of information for the Gap Analysis. The status of the industry EUG and Stakeholders group was summarised in the internal project report Deliverable D2.1 “Survey of End Users” published March 2021.

5.3 PREDIS Data Collection Approaches

In order to identify the gaps of interest (as bounded by the constraints outlined in Chapter 4) in predisposal management, a variety of different information gathering activities were used, as shown in Figure 7.

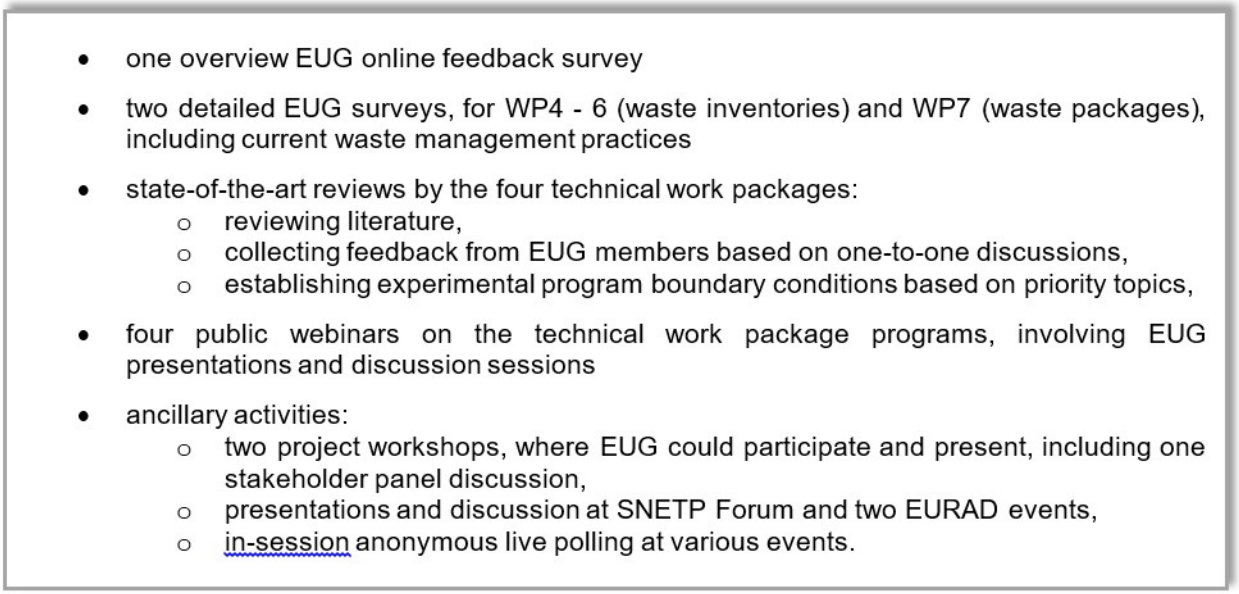


Figure 7. Approaches used to collect input for Phase 2 Gap Analysis.

Each of these activities is described in more detail in the sections below and elaborated on within the next chapter of results. For context of the work packages' technical scope (tasks) and innovation targets, please refer to the summary in Appendix 3.

5.3.1 EUG On-Line Feedback Survey

Shortly after the first PREDIS project workshop held in October 2020, EUG internal and external members were invited to participate in an online survey. Respondents were first asked to indicate which work packages they were interested in and were then asked a variety of questions about various aspects of the orientation of each selected work package. Several of these questions (see below) provided gap analysis input. In total there were 19 respondents from 12 countries to this survey representing waste generating, waste owning and waste managing organisations. As noted earlier, the outcomes of the survey were summarised in the internal project report Deliverable D2.1 "Survey of End Users" published March 2021.

For Work Package 4 (on metallic wastes), participants were asked to respond to three questions with gap analysis implications:

- "What are the primary interests [volume reduction, cost savings, development of treatment and disposal routes for currently untreated wastes, minimising higher level clearance materials and/or other] of your organisation related to metallic waste treatment?
- Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?
- What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?

For work package 5 (on liquid organic wastes), participants were asked to respond to five questions with gap analysis implications:

- "What are the primary interests [volume reduction, cost savings, development of treatment and disposal routes for currently untreated wastes, minimising higher level clearance materials and/or other] of your organisation related to liquid organic waste treatment?
- Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?
- What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?
- Does your organisation have any radioactive liquid organic wastes that could benefit from direct conditioning in a geopolymer-type matrix?
- Is your organisation facing waste acceptance criteria issues for liquid organic wastes or geopolymers containing liquid organics?

For work package 6 (on solid organic wastes), participants were asked to respond to four questions with gap analysis implications:

- "What are the primary interests [volume reduction, cost savings, development of treatment and disposal routes for currently untreated wastes, minimising higher level clearance materials and/or other] of your organisation related to solid organic waste treatment?
- Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?
- What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?
- Is your organisation facing waste acceptance criteria issues for solid organic wastes or geopolymers containing liquid organics?

For work package 7 (on monitoring and storage of cemented waste packages), participants were asked to respond to five questions with gap analysis implications:

- Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?

- What are the main topics [cracks, loss of thickness, change in dose rate, gas production/over pressure within waste packages and/or other], connected with cement waste package degradation that your organisation would like to see detected and monitored as a priority by instrumentation and controls, and be considered during demonstration tests?
- Which durability performance indicators are most relevant?
- Would your organisation be interested in applying (and investing in) digital twin technology to predict the evolution of waste packages at your facility?
- What measurements or analyses are missing from the portfolio of available non-destructive evaluation techniques / monitoring technologies / instrumentation?

5.3.2 Detailed EUG Inventory Surveys

Part of the PREDIS work involves developing a database and better understanding of waste inventories. As well as providing important strategic insight into the magnitude of waste arising around Europe, this inventory also supports identification of priority waste streams for study in PREDIS. The database should be integrated with other existing public knowledge databases, for instance as also collected by EURAD-Routes and the EC initiatives. To facilitate this PREDIS gathering of inventory information, two questionnaires were prepared for completion by PREDIS partners and EUG members who own, manage or generate radioactive wastes. The first was related to work packages 4, 5 and 6 on metallic waste, liquid organic waste and solid organic waste. The second survey was related to work package 7 on monitoring and storage of cemented waste packages.

The aim of the WP4 - 6 questionnaire is to help identify the priority waste streams in each country, and document their quantity, their current state (e.g., raw, containerised, already conditioned and/or packaged), time of future arising, and their radiological inventory. The prioritisation was views from PREDIS perspective with respect to where to invest finances towards RD&D to make the greatest impact in improved predisposal treatment and conditioning steps for certain waste streams. For WP7, the questions concerned 1) the characteristics of cemented waste packages and their storage configuration in order to identify specific needs of the PREDIS End Users, 2) the strategies for managing cemented waste including aspects such as monitoring and managing package degradation and 3) the monitoring systems, data handling, and quality management procedures adopted during storage of cemented waste packages. The questionnaires have been sent to all PREDIS partners and end-users.

To date there have been 11 responses to the WP4 - 6 survey representing radioactive waste inventory information from three EUG members and eight PREDIS consortium partners. Of these, four respondents provided information on metallic wastes, four respondents provided information on solid organic wastes and nine respondents provided information on liquid organic wastes. Regarding WP7 survey, there have been eight responses from EUG members.

The responses from these questionnaires were also interpreted relative to gap analysis considerations. This interpretation aimed at identifying any priority waste streams that were unaddressed by the scope of work packages 4, 5 and/or 6. The survey results from WP7 were integrated to the WP7 state-of-art report. It should be noted that the surveys were applicable to the initial scope of the PREDIS project, and thus issues that were already deemed outside of the scope were not re-addressed by this second phase Gap Analysis solicitation of feedback.

5.3.3 State-of-the-Art Reviews

All four technical work packages have been tasked during the first year of the project with conducting detailed state-of-the-art (SOTA) reviews, to better understand current best practices, limitations and industry challenges. This work has been done by reviewing literature as well as by direct one-to-one (partner to industry) discussions with EUG members and stakeholders. The reviews have led to establishing more specific material selections and boundary conditions for the experimental programs and tasks within the work packages. The reviews along with the responses to the EUG surveys are being compiled and used in the preparation of the following PREDIS deliverables and milestones:

- MS22: Inventory of metallic waste (WP4, month 12)
- MS23: Technologies for decontamination, characterisation, recycling and encapsulation (WP4, month 12)
- D4.1: Metallic waste inventory report (month 18)

- MS32 Reference formulations (WP5, month 9)
- MS35: Experimental protocols for conditioning materials (WP5, M9)
- D5.1: Inventory data on liquid organic wastes (WP5, month 12)
- MS39: Leaching procedure for experiments (WP6, month 12)
- D6.4: Database of solid organic wastes (WP6, month 47)
- D7.1: State-of-the-art in packaging, storage and monitoring of cemented wastes (month 6)
- MS50: Agreement on materials and testing scenarios (WP7, month 12)

For WP4 - 6, these deliverables or milestones are not yet finalised or published (pertaining to the deliverable dates in the above list). The Work Package 7 SOTA report (Deliverable D7.1) is published and available on the PREDIS website https://predis-h2020.eu/publications-and-reports/. Gap Analysis results from these sources are described in Chapter 5.4 and relevant corresponding Appendices per Work Package.

The information collected for producing the SOTA report was also interpreted relative to gap analysis considerations by Work Package 7. This interpretation identified technology gaps and categorised them with respect to source (how and where gaps were identified), classification (waste stream type), phase (characterisation, treatment, conditioning, packaging, storage or transport), priority (i.e. the relative urgency of development work), technology level (the relative level of R&D work needed to fill identified technology gap) and whether such R&D work is within the scope, budget and timeline of the PREDIS project.

More broadly, each technical work package interpreted the information gathered from its own SOTA review and internal gap analysis activities. These interpretations identified technology gaps and categorised them with respect to source (how and where gaps were identified), classification (waste stream type), phase (characterisation, treatment, conditioning, packaging, storage or transport), priority (i.e., the relative urgency of development work to justify financial investments), technology level (the relative level of R&D work needed to fill identified technology gap) and whether such RD&D work fit into the scope, budget and timeline of the PREDIS project.

5.3.4 Technical Webinars

The PREDIS project held four technical webinars over the first three months of 2021 in order to share insights on technical innovation plans from the work packages, hear case studies and discuss industry needs, challenges and priorities. A further objective of the webinars was to inform the PREDIS project gap analysis. The schedule of these webinars was as follows:

- January 19, 13-16 CET: WP7 - Innovations in cemented waste package monitoring and storage
- February 16, 13-16 CET: WP4 - Innovations in metallic material treatment and conditioning
- March 9, 13-16 CET: WP6 - Innovations in solid organic waste treatment and conditioning
- March 30, 13-16 CET: WP5 - Innovations in liquid organic waste treatment and conditioning

Each webinar consisted of two sessions of presentations followed by smaller group discussions to explore issues raised in the formal presentations and to gather end user (and broader) information on future objectives in predisposal waste management, potential barriers standing in the way of meeting those objectives and input on the technologies being developed in the PREDIS work packages. The deliberations of the discussion sessions provided direct feedback to the work packages and input to the gap analysis. A set of key takeaways were derived from the discussion sessions for each webinar. These key takeaways were then further assessed by the associated work packages relative to their scopes of work, as described in Section 5.4 and the relevant Appendices.

The webinars also served to widen access for interaction with the PREDIS project:

> *Overall, 16 different guest presentations from end users were featured during the webinars. A total of 80 self-identified end users, representing 54 organisations from 27 different countries and 157 self-identified general stakeholders, representing 120 organisations from 46 different countries, registered to attend the webinars. The webinars also benefited from extensive IAEA perspectives and insights as every webinar featured IAEA presentations and participation to breakout room discussions.*

Additionally, on-line polling was conducted during the webinars. These polls were aligned with some of the gap analysis related questions asked in the EUG online survey and are used for focus area identification and trend recognition. Similar or related questions were asked in each webinar, to compare responses between audiences and with the feedback gained during the Phase 1 Gap Analysis when preparing the proposal.

During the WP4 webinar on metallic wastes, participants were asked to respond to two on-line poll questions with gap analysis implications:

- What is the biggest challenge [segregation and sorting, classification and characterisation, treatment and conditioning, transport, monitoring and storage, financial issues, regulatory compliance or other] in the predisposal management of metallic waste?
- What should be the primary focus [volume reduction, cost savings, processing speed and efficiency, untreated wastes, minimising secondary wastes, development of mobile or modular treatment options, training and education or other] of near-term R&D related to metallic waste treatment and conditioning?

During the WP5 webinar on liquid organic wastes, participants were asked to respond to two (nearly the same, by design) on-line poll questions with gap analysis implications:

- What is the biggest challenge [segregation, characterisation, treatment, conditioning, packaging, storage, waste acceptance criteria or other] in the predisposal management of liquid organic waste?
- What should be the primary focus [untreated legacy wastes, volume reduction, processing speed and efficiency, minimising secondary wastes, mobile or modular treatment systems, cost savings, training and education or other] of near-term R&D related to liquid organic waste treatment and conditioning?

During the WP6 webinar on solid organic waste, participants were asked to respond to two (nearly the same, by design) on-line poll questions with gap analysis implications:

- What is the biggest challenge [segregation, characterisation, treatment, conditioning, packaging, storage, waste acceptance criteria or other] in the predisposal management of solid organic waste?
- What should be the primary focus [untreated legacy wastes, volume reduction, processing speed and efficiency, minimising secondary wastes, mobile or modular treatment systems, cost savings, training and education or other] of near-term R&D related to solid organic waste treatment and conditioning?

During the WP7 webinar on monitoring and storage of cemented waste packages, participants were asked to respond to two on-line poll questions with gap analysis implications:

- What aspects of predisposal management of radioactive waste [technology demonstration, technology access, minimising secondary wastes, safety, environmental impact, cost reduction, processing speed, training, regulatory compliance, stakeholder confidence and/or other] do you think the PREDIS project should primarily focus on?
- Which monitoring topics [deformation, cracks and voids, corrosion, temperature, gas generation, dose rates, environmental conditions, remote operation, automation, upscaling, data handling, processing and analysis and/or other] are your organisation's goals or objectives related to?

5.3.5 Ancillary Activities

Various meeting events with large numbers of participants have been held that also provided complimentary information to the PREDIS Phase 2 Gap Analysis, especially from in-meeting audience live polling. These were PREDIS workshops, an SNETP forum and two EURAD events.

PREDIS has organised two full-consortium workshops, 19-21 October 2020 and 4-6 May 2021. Both events presented opportunities for engagement with the EUG and gathering feedback relevant to the Gap Analysis. In the first event, four different half-day Work Package specific discussions were held including EUG member participation part of the time. An additional half-day session was also held for a wider stakeholder audience including a stakeholder panel, with the following

- Needs of waste producers, represented by Abderrahim Al Mazoui (EDF, France and SNETP)
- Needs of waste owners, represented by Mark Dowson (Sellafield site, UK)
- Needs of waste management organisations, represented by Irina Gaus (Nagra, Switzerland and IGD-TP)
- International cooperation perspectives, represented by Piet Zuidema (EURAD Chief Scientific Officer)
- International cooperation perspectives, represented by Rebecca Robbins (IAEA, Austria).

The Stakeholder session was summarised in PREDIS Newsletter No. 1 published in November 2020. The second workshop in May 2021 had one half-day session open for EUG participation.

A dedicated Technical Session 6 at the SNETP (earlier Nugenia) annual Forum was held February 2021 (online), including presentations from industry on predisposal current practices. The half-day session also included brainstorming discussions in breakout rooms about priority research needs. The industry presentation topics and invited guest speakers included PREDIS confirmed or potential EUG potential members:

- Fuel cycle closure, D&RDWM, 1 Massimo Sepielli (ENEA, Italy), with Sogin and ISIN Regulator
- Decommissioning and pre-disposal waste handling needs, a French perspective, Clement Bosquier (EDF, France)
- Decommissioning of Ignalina NPP, Dmitrij Ekaterinicev & Jurij Sapoval (INPP, Lithuania)
- Sweden's decommissioning and radwaste perspectives, Andreas Knutsson (Vattenfall, Sweden)
- Sellafield Challenges: Steering the Supertanker, David Connelly (Sellafield, UK)
- Small inventory program needs in decom and waste management, Andrea Rapić (Fund for financing the decommissioning of the Krško NPP, Croatia)

The two events hosted by the EURAD project also included invited presentations by VTT as the Coordinator of PREDIS, where issues about predisposal waste management were covered. These events were the training event in September 2020 and the lunch-and-learn session in October 2020.

In some of the events above (SNETP Forum and EURAD events), PREDIS has used in-meeting, anonymous live polling for multiple choice questions on predisposal radioactive waste needs. Similar questions were also used in the technical webinars, described in the earlier section. These live polls have provided complimentary insights about the similarities or differences in audience opinions for gap analysis topics.

During the Introductory Course on EURAD and Radioactive Waste Management and the Lunch-and-learn session on Synergies of EURAD with the PREDIS project addressing pre-disposal waste treatment, participants were asked to respond to the same two on-line poll questions with gap analysis implications:

- What is your opinion on the greatest challenge [waste segregation and sorting, waste classification and characterisation, waste processing, waste transport, waste interim storage, financing, government policy] in waste pre-treatment?
- What types of waste [metallic waste, graphite waste, concrete waste, solid organic waste, liquid organic waste, other] should we focus on for near-term R&D on treatment technologies (for highest impact/achievement potential)?

During Technical Session 6 of the SNETP Forum, participants were asked to respond to a similar set of on-line poll questions with gap analysis implications:

- What is the biggest challenge [segregation and sorting, classification and characterisation, treatment and conditioning, transport, monitoring and storage, financial issues, regulatory compliance, other] in predisposal management of radioactive waste?
- For which waste type [metallic, graphite, solid organic, liquid organic, other] would near-term R&D result in the greatest impact on predisposal management activities?

5.4 Data Analysis

5.4.1 EUG On-line Feedback Survey

The survey was conducted using the web-based software tool Webropol (https://webropol.com/) and responses to the standardised questionnaire were organised and evaluated using Microsoft Excel.

Of the 19 respondents to the survey, 15 expressed an interest in WP4, 11 in WP5, 9 in WP6 and 14 in WP7, which likely corresponds to the particular waste inventories under their purview.

Lists of the open-ended responses to questions in the EUG on-line feedback survey with gap analysis implications are provided, in order of receipt, in tables under the heading "EUG On-line Feedback Survey" in Appendices 3 - 6 for WP4-, WP5-, WP6- and WP7-Related Gap Analysis Results, respectively. These responses are categorised relative to the current scope of work in the relevant work packages, as being **1) already in-scope**, **2) not in-scope, but could be**, **3) not in-scope and can't be, but could be promoted to the SRA** or **4) not in-scope and shouldn't be.**

5.4.2 Detailed EUG Inventory Surveys

The responses to the WP4 - 6 radioactive waste inventory questionnaire were interpreted relative to gap analysis considerations. To this end it was noted that no unexpected waste streams were flagged in the responses to the inventory questionnaire and that indeed, essentially all the waste streams designated by the respondents are being addressed by the original scope of each technical work package.

More specifically:

- The main metallic waste types identified are steel and Al as both sheets and pipes. These materials, in both simple and complex geometries, are earmarked for testing in WP4. Additionally, some of the waste streams in the inventory are mixed and will require sorting and segregation which also falls within the scope of the characterisation task in WP4.
- The candidate liquid organic wastes to be tested in WP5 were oils, solvents and scintillation cocktails and these correspond to the most commonly identified liquid organics in the inventory questionnaire.
- The main solid organic wastes identified are resins, plastic (e.g., PPE) and filters, and treatment schemes are being tested on such wastes in PREDIS. Additionally, bitumen was identified as a major waste stream and it is uncertain whether the processes being tested in PREDIS would be suitable for processing this waste. Plasma treatment was identified in THERAMIN as a good candidate for treating bitumen. In any case, the EUG members managing such waste made the strategic decision to focus on cellulosic wastes for the purposes of the PREDIS project.

The results of the WP7 detailed EUG survey are integrated to the WP7 SOTA report, described in the next section.

5.4.3 State-of-the-Art Reviews and Associated Gap Analysis Activities

As indicated above, over the course of the first months of the project, each technical work package pursued its own state-of-the-art (SOTA) review and associated gap analysis activities. Each technical work package gathered the information via various means and interpreted it in terms of the gap analysis. These interpretations identified technology gaps and categorised them with respect to source (how and where gaps were identified), classification (waste stream type), phase (characterisation, treatment, conditioning, packaging, storage or transport), priority (i.e., the relative urgency of development work), technology level (the relative level of R&D work needed to fill identified technology gap) and whether such R&D work is within (or within reasonable reach of) the scope, budget and timeline of the PREDIS project (yes or no). More specifically, the priority or relative urgency of filling an identified gap was categorised as high, medium or low with respect to time where high = 0 to 5 y, medium = 5 to 10 y and low = 10 to 20 y and the technology level indicates how close the identified gap is to being filled by proven, deployable technology as near, partway or far with respect to the level of R&D work still required.

Each technical work package documented their gap analysis information collection and interpretation activities in short reports which are compiled into this report in Chapters 6.3, 6.4, 6.5 and 6.6 for Work Packages 4 to 7,

respectively. The specific gap analysis results from these activities are tabulated in Appendices 4, 5, 6, and 7 for Work Packages 4 to 7, respectively. The colour scheme used to visualise the gap analysis topics and issues for the EUG on-line feedback survey is employed for the same purposes with these results.

For Work Package 7, since a detailed SOTA report was published in the first six months of the project, there is also a more elaborately detailed gap analysis available. This analysis followed the same format for identifying and categorising technology gaps as described above. The specific gap analysis results from information collected for producing the WP7 SOTA report are tabulated in Appendix 7 for WP7-Related Gap Analysis Results. The colour scheme used to visualise the gap analysis topics and issues for the EUG on-line feedback survey is employed for these results as well.

Information and analysis from the SOTA reviews by WP4 - 6 will be formally reported in future milestones and deliverables.

5.4.4 Technical Webinars

The four webinars included 23 presentations by project partners and 18 presentations by external EUG or more general stakeholders. The data collected during the webinars was mostly qualitative in nature, though a few live poll questions were used. The agenda of the webinars and the summary key messages (and poll results) from each event can be found on the PREDIS website at https://predis-h2020.eu/events/. In total, the webinar registration included over 400 persons from 40 countries, with the composition being approximately 46 % PREDIS partners and 54 % EUG or general Stakeholder participants. On average, 115 persons attended each webinar. Key insights were provided in every webinar by IAEA predisposal waste management team leader Rebecca Robbins, which also added credible views from a wider worldwide perspective. The average feedback score from 85 respondents of the webinar participants was over 4.35 out of 5.0, with the same six questions asked about communication for the event, technical quality of the sessions and breakout rooms, and usefulness of the breakout room discussions.

Sets of key takeaways were derived from the discussion sessions for each of the four technical webinars. Topics that were outside the scope of the technical work packages could also be discussed in the webinars, raised by industry presentations or in the discussion groups. These key takeaways from the webinar presentations, live polls and discussion groups were then further assessed by the associated work packages relative to their scopes of work. Lists of the key takeaways with gap analysis implications are provided in tables in Appendices 3 - 6 for WP4-, WP5-, WP6- and WP7-Related Gap Analysis Results, respectively. These responses are categorised relative to the current scope of work in the relevant work packages, as being **1) already in-scope**, **2) not in-scope, but could be**, **3) not in-scope and can't be, but could be promoted to the SRA** or **4) not in-scope and shouldn't be.**

5.4.5 Ancillary Activities

Three sets of ancillary activities were implemented: 1) PREDIS workshops, 2) an SNETP Forum session and 3) two EURAD associated events. In each of these technical online events, live polling specific to the PREDIS project gap analysis was carried out which indicated that the biggest generic challenges identified were waste classification and characterisation, and waste processing (treatment and conditioning).

The results of the live polling for the EURAD and SNETP events are found in Appendix 8. The results of the live-polling for the PREDIS technical webinars are available on the PREDIS website at https://predis-h2020.eu/events/ by navigating to the webinar summary of interest. All of the live polling results are summarised as follows:

- For the non-waste specific events (EURAD, SNETP), the majority of respondents consistently considered classification and characterisation, waste processing, and segregation and sorting (in rotating order) to be the biggest challenge in waste pre-treatment. Additionally, poll respondents at these events regularly agreed that the top two wastes to be focussed on for near-term R&D were always from among liquid organic wastes, solid organic wastes and metallic wastes.
- For the WP4 webinar, the majority of respondents consistently considered treatment and conditioning and classification and characterisation (in that order) to be the biggest challenge in the predisposal management of metallic waste. Additionally, poll respondents at this event agreed that volume

reduction should be the primary focus of near-term R&D related to metallic waste treatment and conditioning.

- For the WP5 webinar, the majority of respondents considered conditioning and waste acceptance criteria (in that order) to be the biggest challenge in the predisposal management of liquid organic waste. Additionally, poll respondents at this event agreed that untreated legacy wastes should be the primary focus of near-term R&D related to liquid organic waste treatment and conditioning.
- For the WP6 webinar, the majority of respondents considered conditioning and characterisation (in that order) to be the biggest challenge in the predisposal management of solid organic waste. Additionally, poll respondents at this event agreed that volume reduction should be the primary focus of near-term R&D related to solid organic waste treatment and conditioning.
- For the WP7 webinar, the majority of respondents considered that technology demonstration should be the primary focus of the project. Additionally, poll respondents at this event agreed that data handling, processing and analysis is the most important topic.

These results are consistent with both the general and specific outcomes of the work-package specific analysis from EUG surveys, state-of-art-reviews and webinars. They also support the phase 1 gap analysis that identified the most critical predisposal waste management challenges that should be addressed by the PREDIS proposal application.

From the SNETP technical event, approximately 65 people attended the online session. The outcomes of the SNETP Forum are summarised in a Policy Paper by Technical Area 5 leadership (including NNL and VTT as PREDIS partners), expected for publication in May 2021. The key points summarised included the following RD&D topics:

- Application of the waste hierarchy to avoid/minimise waste generation: through smart design, appropriate material selection, operational measures, and designing for decommissioning.
- Establishment of improved (Predisposal) treatment technologies (thermal or other) to reuse/recycle materials, minimise waste volumes and to develop robust and passive waste forms. Specific waste focus areas include, organic wastes, metallics, contaminated concrete, irradiated graphite, etc.
- Development of characterisation techniques for waste inventory assessment, and plant/facility assessment to aid planning for decommissioning and waste management.
- Development of waste segregation/sorting, advanced decontamination techniques and optimised measurement/assay methods to enable a circular economy where appropriate.
- Application of transformative technologies to optimise decommissioning scenarios: for example, digitalisation, supercomputing, artificial intelligence, in-situ characterisation and robotics.
- Identification of synergy effects for multi-unit sites or fleet-wide D&D projects, standardisation of approach, use of mobile treatment facilities and optimisation of post-operational phase.

Many of these issues are in-line with the PREDIS technical WP objectives, while others can be addressed further in the Strategic Research Agenda of PREDIS. SNETP is also in the process of renewing their Strategic Research Agenda over the next 18 months (2021-22), and thus can be an avenue for further cooperation.

6 Results and Main Findings

The detailed results and mapping of all gaps identified in PREDIS activities are presented in Appendices 4 to 7 for Work Packages 4 to 7, respectively. Each of these Appendices contains a breakdown of the results from the various activities, e.g., SOTA reviews, webinars and surveys. The following sections in this Chapter provide a summary of the identified gaps (6.1), an overview of the gap handling procedure (6.2) and the short reports documenting the gap analysis information collection and interpretation activities for Work Packages 4 to 7 (6.3, 6.4, 6.5 and 6.6, respectively). For reference, the work packages' technical scope (tasks) and innovation targets as originally described in the PREDIS proposal and project starting point are shortly summarised in Appendix 3.

6.1 Gap Identification Summary

A total of **133** unique topics/issues meeting the definition for gaps of interest outlined in Chapter 4 were identified by the gap analysis activities described in Chapter 5. Of these, **40** were associated with WP4 on metallic waste, **29** were associated with WP5 on liquid organic waste, **26** were associated with WP6 on solid organic waste and **38** were associated with WP7 on the monitoring and storage of cemented waste packages.

Of the 40 topics/issues associated with predisposal of metallic wastes, 26 were categorised as being **already in-scope**, 2 as being **not in-scope, but could be** and 12 as being **not in-scope and can't be, but could be promoted to the SRA**. No topics were categorised as being **not in-scope and shouldn't be.** The disposition of identified gap analysis predisposal topics/issues for metallic waste is shown in the pie chart in Figure 8.

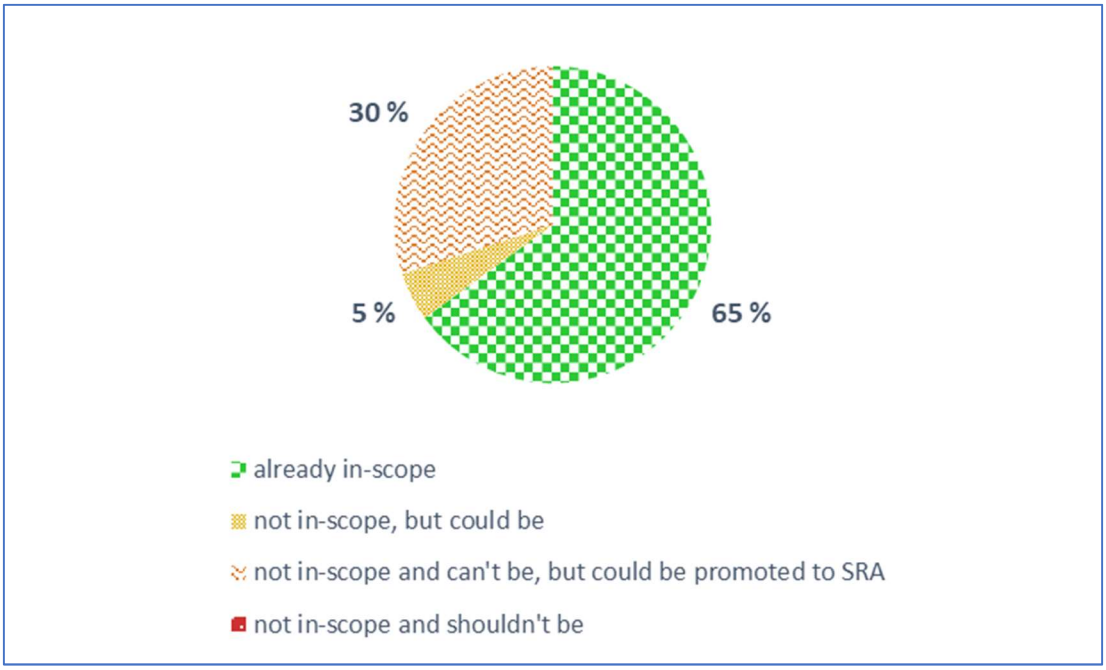


Figure 8. Disposition of the identified gap analysis predisposal topics/issues for metallic waste relative to PREDIS project scope.

Of the 29 identified gap analysis topics/issues associated with predisposal of liquid organic wastes, 18 were categorised as being **already in-scope**, 0 as being **not in-scope, but could be**, 10 as being **not in-scope and can't be, but could be promoted to the SRA** and 1 as being **not in-scope and shouldn't be.** The disposition of identified gap analysis predisposal topics/issues for liquid organic waste is shown in pie chart in Figure 9.

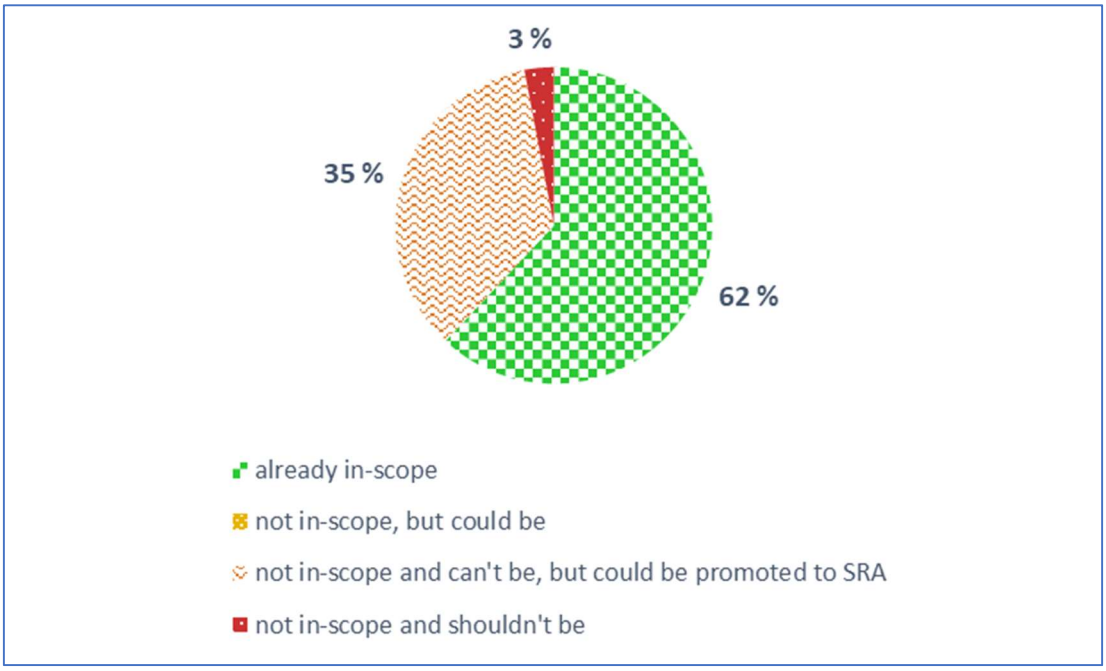


Figure 9. Disposition of the identified gap analysis predisposal topics/issues for liquid organic waste relative to PREDIS project scope.

Of the 26 identified gap analysis topics/issues associated with predisposal of solid organic wastes, 13 were categorised as being **already in-scope**, 3 as being **not in-scope, but could be**, 7 as being **not in-scope and can't be, but could be promoted to the SRA** and 3 as being **not in-scope and shouldn't be.** The disposition of identified gap analysis predisposal topics/issues for solid organic waste is shown in the pie chart in Figure 10.

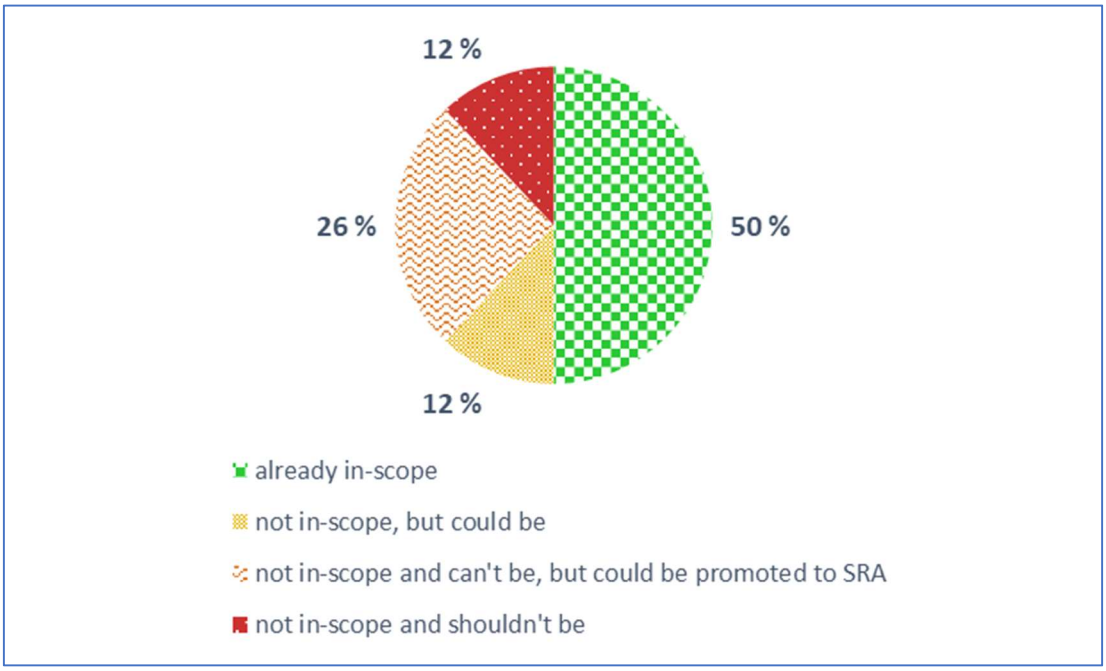


Figure 10. Disposition of the identified gap analysis predisposal topics/issues for solid organic waste relative to PREDIS project scope.

Of the 38 identified gap analysis topics/issues associated with monitoring and storage of cemented waste packages, 20 were categorised as being **already in-scope**, 9 as being **not in-scope, but could be**, 5 as being **not in-scope and can't be, but could be promoted to the SRA** and 4 as being **not in-scope and shouldn't be.** The disposition of identified gap analysis predisposal topics/issues for monitoring and storage of cemented waste packages is shown in the pie chart in Figure 11.

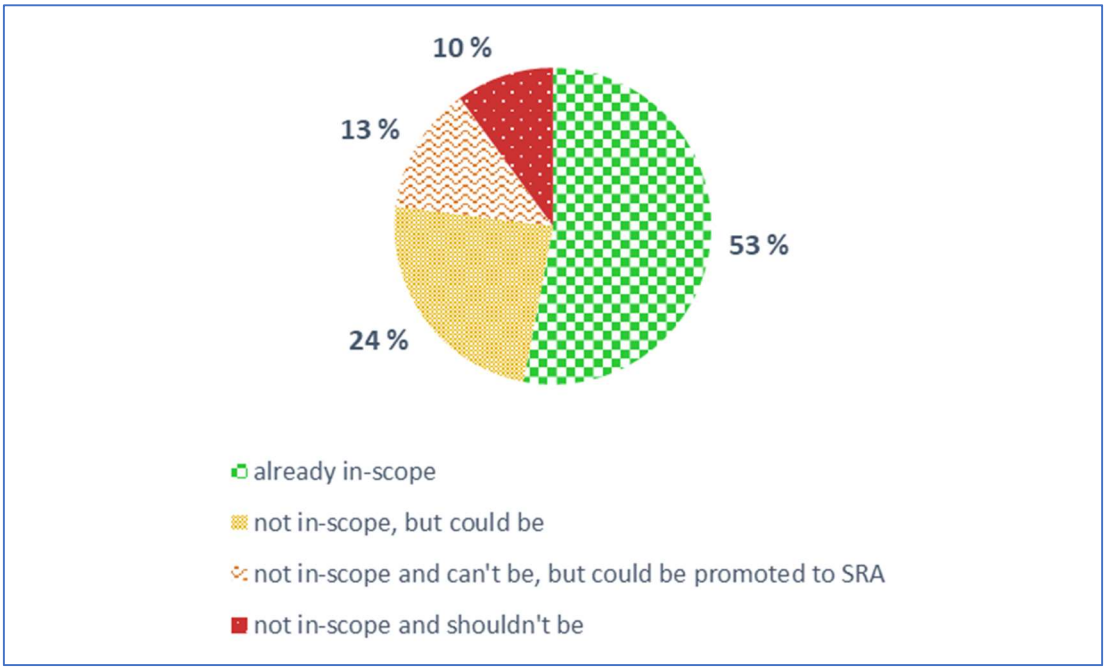


Figure 11. Disposition of the identified gap analysis predisposal topics/issues for monitoring and storage of cemented waste packages relative to PREDIS project scope.

6.2 Gap Handling Overview

The **77** gap topics/issues categorised as being **already in-scope** of the PREDIS project are currently the subject of on-going research and development work in the project and therefore a plan exists to address them. For the **14** gap topics/issues categorised as being **not in-scope, but could be** of the PREDIS project, the individual work packages will determine whether and how they will be handled in terms of integration into the research & development work of the project. For the **34** gap topics/issues categorised as being **not in-scope and can't be, but could be promoted to the SRA** of the PREDIS project, Work Package 2 will determine whether and how they will be incorporated into the SRA. No actions will occur regarding the **7** gap topics/issues categorised as being **not in-scope and shouldn't be**, as they are completely outside of the scope of the PREDIS project. The next sub-sections provide more technical insights about the gaps and how they link to the existing and potentially adapted scope of the four technical work packages. Chapter 7 provides an overall summary of the Gap Analysis results and the future steps in the PREDIS project regarding these finding. The summary points of the gap handling plan will also be covered in the first periodic reporting of the project (at month 12) and discussions with the EC, before the update of the Description of Action.

6.3 Gap Handling in Specific Work Packages

6.3.1 Metallic Waste Gap Analysis (WP4)

Decontamination

Large volumes of metallic waste are generated during decommissioning and to a lesser extent during operation of nuclear installations, among them steels, Ni-alloys and other metals. According to the principle of circular economy, it is important to recycle as much of these materials as possible. A large volume of material can be reclaimed through decontamination of these wastes. This reclamation allows saving storage and disposal resources as well as reducing costs.

Within WP4 of the PREDIS project, it is planned to optimise known chemical/gel decontamination processes with an emphasis on the management of treatment effluents. Constructive discussions with end-users as well as feedback from the survey organised within Task 4.3 and from the webinar held on WP4 activities the following topics were highlighted:

1. Optimisation of chemical decontamination
2. Management of secondary wastes from chemical decontamination
3. Mobile waste treatment

Topics 1 and 2 are being addressed by PREDIS WP4 and will be complemented by including an LCA approach when possible. Special attention will be paid to WAC via interactions with WMOs. Topic 3 is considered important but not covered nor financed within the PREDIS project. It should be promoted to the SRA.

Characterisation

Before and after dismantling and cutting of the reactor components into segments, precise and accurate characterisation is necessary for sorting of the metallic waste into different management routes. The aim is to decide if decontamination is needed (clearance criteria have not been met and can be met after decontamination) as well as to select the most efficient decontamination process.

To optimise the characterisation and sorting procedure, measurement uncertainties should be reduced and thereby allow the management of metallic waste to be more efficient. Also, the reduction of the uncertainty in the clearance measurements will increase the volume of metallic waste for recycling which means significant reduction in costs. Procedures based on Monte Carlo simulations as well as on gamma camera technology or on the use of a number of plastic scintillation detectors are proposed for reduction of the measurement uncertainty. In WP4 Task 4.5, a new measurement layout for gamma spectrometry measurement is proposed for significant reduction of the characterisation uncertainty. The ambition within the PREDIS project is the optimisation of the characterisation methodology for sorting the waste streams, a pre-requisite for allowing the recycling of a maximum volume of metallic waste following their decontamination. This is in line with the circular economy strategy of Europe.

Conditioning

The operation and decommissioning of nuclear facilities generate a large volume of radioactive metallic waste (steels, Al, Mg, Zr, Zn, U, Be, W). Prior to disposal, the radioactive waste must be conditioned in a stable and confined form. Concrete encapsulation is one strategy to manage the low- and intermediate-level waste by isolation from the environment. The major risk of this type of metal confinement is the aqueous corrosion, resulting in hydrogen release under (anoxic) disposal conditions.

Gap analysis with regard to the encapsulation of the reactive metallic waste includes many aspects such as the right chemical formulation as well as reducing the cost. Hence, the priority topics for the PREDIS WP4 activities on conditioning to be carried out are as follows:

1. Optimise magnesium phosphate cements (MPC) formulation for metallic waste encapsulation.
2. Characterise the MPC (mechanical properties, pH monitoring, leaching, irradiation).
3. Optimise the MPC cost for use on an industrial scale.
4. Study the reactivity of the inventoried metallic waste (Al and Be) but also the drum (low carbon steel). Determine the volume of hydrogen produced as a function of the formulation and compare it to the one measure in a conventional cement (Portland type cement).

All of these studies have to be done considering available literature, the waste acceptance criteria imposed by the end-users and the disposal environment conditions.

6.3.2 Liquid Organic Waste Gap Analysis (WP5)

Work Package 5 of the PREDIS project focuses on the development of technical solutions for the direct conditioning of radioactive liquid organic waste by immobilisation in a geopolymer matrix or related alkali-activated materials. The project should make it possible to highlight the advantages of these technical solutions and the applicability of these conditioning methods, in particular for liquid organic wastes currently without a solution (i.e., those wastes that cannot be incinerated).

Feasibility. In order to show their feasibility, these technical solutions must be optimised to surpass other possible alternatives such as cement or polymer-based produces such as NOCHAR. It is with these two reference materials that the performances of the innovative matrices developed within the framework of the PREDIS project (Task 5.3) will be compared. The evaluation of the benefits provided by geopolymers must be made in economic terms, relying in particular on the cost of raw materials and the increase in waste loadings in order to limit the number of containers produced to be disposed (Task 5.5). In the PREDIS project, ambitious waste load loadings of more than 20 to 30% in volume will be targeted.

Versatility. Direct conditioning solutions are simple to implement: the mortar can be prepared in a non-radioactive environment upstream of the incorporation of the radioactive liquid organic waste. Such technical options must show their versatility by allowing the treatment of radioactive organic liquid waste of various natures: oils, solvents, scintillation cocktails, etc. These wastes, identified as the most numerous and problematic in Europe (Task 5.2), are part of the reference waste on which the matrices developed within the framework of the PREDIS project will be tested (Task 5.3). The partners will be free to add more specific waste relevant in in their respective national context. The associated process options must make it possible to accommodate deposit volumes that can vary from a few litres to several tens of cubic meters.

Sustainability. The sustainability of the processes must also be demonstrated by the ability to secure material supplies from various sources of raw materials, in particular locally sourced materials limiting the number of actors in the logistics chain. It is also a question of promoting the circular economy by using recycled materials, which are currently not at all or poorly recovered. Many of the raw materials used in the PREDIS project will be supplied nationally by the partners, which will also allow the comparison of the relative qualities of various sources of supply for such materials. Materials from recycling will also be used.

Disposability. Once produced, the disposability of geopolymers and their compliance with WAC, when they are defined, is of paramount importance. If these matrices are already acceptable or accepted in certain countries of the European Union, many Waste Management Organisations ask to strengthen the robustness of the knowledge of these matrices with regard to their behaviour in long-term interim storage, then with disposal operational safety and post-closure safety. This involves evaluating the chemical reactivity and durability of these matrices so as to better understand the interactions between the matrix and the organic liquid waste it contains as well as the evolution of the geopolymer properties over time and therefore its radionuclide containment capacities. Then, the performance requirements in terms of retention of binder early age mechanical properties, resistance of binder to attack by relevant environmental factors and compatibility with geochemical in-situ conditions in a repository must be defined beforehand and ensured. It is also necessary to define the acceptable levels of release or leachate of encapsulated wastes and binder constituents. An important part of WP5 is dedicated to the characterisation of the matrices developed within the PREDIS project: study of the chemical durability under various conditions, of the leachability of radionuclides and of the behaviour to irradiation (Task 5.4). The PREDIS project will therefore provide a great deal of scientific knowledge contributing to the acceptability of geopolymers and related materials in nuclear repositories throughout Europe.

Assessment of identified gaps

The PREDIS project aims to increase the interest in utilising geopolymers and related alkali-activated materials for the direct conditioning of radioactive liquid organic waste and must therefore endeavour to demonstrate that it is:

- a feasible technical solution, with no risks,
- applicable to the diversity of organic liquid waste streams,
- sustainable both economically and in terms of security of consistent supply,
- and that the matrix produced have sufficient properties, performance and safety to be disposable.

Once the preceding elements have been demonstrated, the processes implementing these conditioning techniques must be adapted to waste of various types and quantities.

6.3.3 Solid Organic Waste Gap Analysis (WP6)

Descriptions of identified gaps

Waste producers and waste management organisations are faced with the management of low and intermediate-level radioactive solid organic waste (RSOW) streams. Solutions already exist for the long-term management of organic waste streams and they can be safely disposed for some of them. The aim is to investigate news processes leading to safest and cheapest solution. Nevertheless, it exists a large amount of RSOW for which the current conditioning methods generate waste forms whose safe long-term storage and disposal is difficult to achieve and / or demonstrate, because they are considered not sufficiently stable and / or too highly reactive in alkaline conditions expected to prevail in many final repositories. The identified gaps listed below are the ones appearing the most urgent in the process for the management of such waste streams at the European level.

Specific to WP6, the gap analysis was initiated and based on the outcomes of the THERAMIN project (2016-2020), where the benefit of the thermal treatment on the volume reduction and the destruction of the organic compounds was proved (free access, report http://www.theramin-h2020.eu/).

Assessment of identified gaps

Because of the large variety and the different options already investigated or applied by the Waste Management Organisations in Europe, but outside also, for the treatment and the management of RSOW, a clear overview about the inventory (nature and quantity), the priority level and the possible or current treatment has to be established.

- Gap 1: Radioactive Solid Organic Waste inventory (nature of the waste)

The type and the nature of RSOWs are diverse, they can be raw materials without any treatment and also wastes that have already been conditioned. The gap is to perform the strategic overview of the RSOW for the partners included in PREDIS and to extend the list of thermal technologies actually available or currently under development that are suitable for the treatment of the RSOW. After the first survey sent to the WMO, a ranking was established regarding the type of RSOW that should be considered within the project. They are:

  - Organic-based Ion Exchange Resins (IER). The amount is continuously increasing, and solutions should be proposed for their immobilisation, especially by using thermal treatment that is expected to contribute to a (large) volume reduction. A re-evaluation of the waste classification could be necessary since it results in a ‘concentration’ of radioactivity and the conditioned waste package can no longer be classified as Low and Intermediate-Level Waste but as High-Level Waste.

  - Common cement wastes (as for example the legacy waste where the materials were compacted prior the packaging) containing organic compounds like consumables or other materials like wood. This is typically the case for a lot of historical waste where the composition of the waste is not exactly known.

  - Already conditioned organic waste forms like polymerised waste and bituminised waste where an organic matrix was used to stabilise different inorganic or organic primary waste streams. Unfortunately, the risks associated with such matrices (combustion in case of accidental fire) or chemical reactions occurring after several decades (swelling of bituminised wastes) force the WMOs to take action and condition the wastes.

- Gap 2: Thermal treatment identification

During the THERAMIN program, several processes were tested and have proved the feasibility and the benefit of thermal treatment. Based on the achievements of the program, it was recommended to continue the effort by improving the technologies and by increasing their TRLs. In PREDIS, this effort continues, and other processes are investigated thanks to their promising and innovative aspect and also because they are associated with the immobilisation processes that will be described in the next section. The promoted technologies are:

- Plasma incineration. The RSOW is incinerated and immobilised in a single reactor leading to a glassy-type material. For example, SIIEG will produce samples from the treatment of Ions-Polymers resins.

- Incineration / Gasification. This process, developed by VTT, already proved its efficiency during THERAMIN for the treatment of high organic matter containing radioactive waste leading to the production of ashes and of “clean gas” that may use for energy production. The best options for the immobilisation of the produced ashes will be investigated using geopolymer or cement-based materials (section 2.1.3). Here, the gap is to prove the feasibility of the incineration / gasification of bituminised waste leading to a TRL 2 to 4 during the duration of the program.

- Hot Isostatic Pressing. The process was also investigated during THERAMIN and remains encouraged by the End Users. The value of the process lies in the capacity to retain volatile radionuclides and to produce a glassy-type material to be packaged in a metallic canister. Several gaps are identified: the feasibility of the technology using different types of initial materials and therefore achieving a versatile technology, but also to prove the feasibility of the process at the industrial level by upscaling the method thanks to the collaboration between USFD and NNL. In term of TRL, the intention is to move from 2 to 4 using radiotracer.

- Molten Salt Oxidation. Already used for the treatment of the Radioactive Liquid Organic Waste (WP5), CVRez intends to demonstrate the feasibility of the treatment of IERs and to increase the TRL from 4 to 6 by immobilising the residue obtained after the treatment using binders. Since this technology already exists and is applied for the liquid waste, the process presents a great interest for the treatment of the solid wastes.

- Wet Oxidation. Promoted by USFD and also investigated by POLIMI, this advanced process has to be developed for the treatment of spent IERs and condition the 14C inventory for safe disposal. The residue will be immobilised either HIP by USFD or by using binder by Polimi. During the course of PREDIS program, the TRL should increase from 2 to 4.

- Gap 3: Suitable matrices for the immobilisation of the thermally treated waste

For most of the processes included in WP6, a conditioning step is necessary for the immobilisation of the secondary wastes (ashes, residues, etc.) produced after (thermal) treatment. Until now, the most common binders for the immobilisation of the (treated-) waste are cement-based materials. However, it appears that geopolymer matrices can have properties that increase the stability, the durability and the loading of the treated wastes and also lower the of production cost by using natural compounds. Nevertheless, cement-based materials remain the most common option for the immobilisation of the treated waste. The gap here is to compare the performance of the two types of binder.

Since it is commonly agreed that glassy-type materials are a good matrix for the immobilisation of radioactive wastes (for example High Level Wastes), the feasibility demonstration of embedding thermally treated wastes in such matrices is in the interest of the WMOs. CEA will investigate the glass coating of ashes from IER incineration. The process is quite new and the TRL should increase from 1 to 4.

- Gap 4: Durability and stability evaluation of the conditioned wastes under disposal conditions

A systematic assessment of the durability and the stability of the selected conditioned wastes is required. According to WAC (if available, not obvious for the geopolymer binder), the key parameters influencing the stability and durability under representative disposal conditions will be identified.

Since most of the partners carry out this evaluation under their ‘national’ requirements, and in many cases using different conditioned wastes (as for example the expected composition of the solution and the prevailing redox conditions can be different from one repository to another), which makes an overall evaluation of the benefit of the technologies and the immobilisation processes difficult. Therefore, a common approach is needed by defining a reference protocol and experimental conditions.

Following the recommendation of the EUG, this performance evaluation should be done in the most representative conditions of the disposal system / sites, namely at high pH and not in deionised water at it was done in the past or at high temperature.

The gap is to define common protocol and experimental conditions that will satisfy most of the WP6 partners, allowing the evaluation of the performance of the end products. Since geopolymer and cement-based materials are used in WP4 and WP5, it is recommended to use this reference protocol as much as possible.

- Gap 5: Development of a computational tool

In order to evaluate the matrix performance associated with each technology combined with the large variety of RSOW and the different binder options for their immobilisation, a systematic study of the end products is not conceivable. It would be very costly and time consuming. One option would be the development of a computational tool allowing each EUG to take the decision about the best option for their own problematic wastes according to their national constraints.

- Gap 6: Characterisation of the RSOW

Over the last several years, the level of details regarding the composition of RSOWs has increased. However, for the legacy / historical wastes compositions are far less documented which poses problems for their management and/or conditioning. The characterisation of such wastes was addressed several times during the different interactions EUG – PREDIS, but it is not the intention of WP6 to characterise the initial waste as it is the subject of other projects such as CHANCE or EURAD-ROUTES.

Ranking of identified gaps (see “Summary Table from WP6 Internal Gap Analysis Report” in Appendix 6)

Gaps 1 to 4 are important and should be brought directly into PREDIS since they are linked together. For example, some countries are currently using the direct route for the immobilisation of the IERs, without (thermal) treatment. The aim is to provide relevant information on the advantages of the treatment prior to immobilisation in order to improve the process and / or to give guidance to WMOs on the most efficient and safe way to treat the RSOWs

  - Is it safe enough and economically attractive to immobilise this type of waste without (thermal) treatment or is it preferable to treat them first?
  - If treatment is preferable or unavoidable, which treatment? A chemical degradation or a thermal treatment leading to secondary waste requiring an immobilisation or a ‘single process’ such plasma incineration providing an immobilised and final end-product?
  - If incineration or chemical degradation is favoured, which immobilisation process is better? HIP with the retention capacity of the volatile radionuclides or the use of binders (geopolymer vs cement-based materials)?

Gap 5 (computational tool) is certainly very useful but probably can’t be achieved within the 4 years of the project. Preliminary work will be initiated in PREDIS and should be promoted further via the SRA. It will be ‘under construction’ at the end of PREDIS because this tool will need lot of information for the model calibration and to provide reliable information afterwards.

Gap 6 is included in the WP6 description, but some questions will remain open due to the different routes for the treatment of the RSOW which are not at the same maturity level and it will be difficult to provide a full comparison.

6.3.4 Concrete Packages and Monitoring Gap Analysis (WP7)

Evaluation and Assessment

The incoming information (minutes, notes on the discussions with end users) from the January WP7 webinar was analysed by Timothy Schatz (VTT) on behalf of the MT. The evaluation (comparison to PREDIS work program and information given by WP7 partners) was done by the WP7 leader (Ernst Niederleithinger, BAM). For the categorization, three types were found (already in scope, not in scope, but can and maybe will be and not in scope and can’t be). The results are compiled in the “WP7 - Categorised Webinar Takeaways” table in Appendix 7 (following the general colour scheme outlined above).

Independently, the State-of-the-Art report including the end-user questionnaire and all other available information was collected, sorted and evaluated by the T7.2 team (lead by Stefania Uras, SOGIN). The same team also provided a classification of all identified gaps (based on waste stream classification, predisposal phase, priority, technology level and PREDIS project relevance).

Lastly, two additional gaps, sourced purely as end user needs, are presented in the "WP7 Internal Gap Analysis Issue Categorisation" table in Appendix 7 (following the same colour scheme).

For Work Package 7 a comprehensive SOTA report (Deliverable D7.1) is published and available on the PREDIS website https://predis-h2020.eu/dissemination/. This report was also taken into account for the categorisation of the gaps mentioned below. The identified gaps can be sorted into three categories (WP leader, confirmed by task leaders and partners):

1) *Gaps that are PREDIS relevant and not in the work program but are dealt with in other research projects*: For these gaps (7, 10 and 11 in "WP7 SOTA Report Gap Analysis Issue Categorisation," Appendix 7), technologies are under development in the projects MICADO or CHANCE. PREDIS will have a MoU with both projects asap. The WP7 team plans to invite selected CHANCE and MICADO partners to the next WP7 workshop to ensure that data from their measurement technologies could also be used in practical implementations of the WP7 digital twin and data/decision platforms after the end of PREDIS (open interface of PREDIS data deliverables).

2) *Gaps that are PREDIS relevant and should be brought into the WP7 work plan*: Gap 3 in "WP7 - Categorised Webinar Takeaways" (Appendix 7) and Gap 1 in "WP7 SOTA Report Gap Analysis Issue Categorisation" (Appendix 7) was emphasised by several end users. Internal sensors would be required for this purpose, potentially as an extension to the RFID technology to be developed by VTT/BAM. Gap 13 in "WP7 SOTA Report Gap Analysis Issue Categorisation" (Appendix 7) is not a part of the work program of PREDIS (and can't be due to lack of resources), the technologies developed in WP7 should be evaluated for their potential of mobile/robotic deployment in T 7.6.

3) *Gaps, which are already part of the PREDIS WP7 work program, but which should be given more emphasis*: Gap 3 in "WP7 SOTA Report Gap Analysis Issue Categorisation" (Appendix 7) is mentioned in the PREDIS WP7 work plan without being specific. The work plan should be extended and clarified on this point.

4) *Gaps that should be left out of PREDIS*: Gap 5 in "WP7 - Categorised Webinar Takeaways" (Appendix 7) is beyond the scope of PREDIS. There are too many local and national boundary conditions to be considered. Thus, this type of analysis must be made by follow up national projects. However, WP7 T7.6 will give guidance on the costs of the new technologies as an input to this analysis via the LCC/LCA activities in WP2. For Gaps 5 and 9 in "WP7 SOTA Report Gap Analysis Issue Categorisation" (Appendix 7), commercial sensors are already available for leakage and condensation detection. The T7.5 data platform will propose open interfaces for any kind of additional sensors to be integrated in a practical implementation platform after PREDIS.

5) *Gaps, which are already part of the PREDIS WP7 work program*: Gap 14 in "WP7 SOTA Report Gap Analysis Issue Categorisation" (Appendix 7) is included in T7.4 to validate models for Digital Twin/prediction. Muon technology might give information about package content. More research on legacy waste package characterisation is done in projects such as MICADO.

All other gaps are in the work program, but limitations due to time and budget may apply.

<u>Consequences</u>

WP7 recommends adapting the work plan to address (where possible) identified gaps:

- WP7, T7.3: The list of the parameters to be measured by embedded and externally attached sensors should be appended with "internal corrosion" (of a metallic container)" and "external corrosion (of a metallic container)" as well as "pressure within a waste package, potentially damaging the container". These parameters can potentially be measured by the RFID systems to be developed by VTT/BAM.

- WP7, T7.3: The parameter “condensation” should be added to the external RFID sensing system (UNIPI), at least in a sense that the potential of adding an appropriate sensing module is explored.
- WP7, T7.4: The work program of the digital twin technology should take the potential of measured data into account, which will be delivered by systems such as those developed in CHANCE, MICADO as well as data, coming from commercially available sensing systems
- WP7, T7.5: The database should include a prototype of additional (non-PREDIS) sensing systems
- WP7, T7.6: The demonstration task should explore the possibility of joint demonstrations of certain sensing systems from MICADO, CHANCE and PREDIS (e.g. muon imaging). The potential of robotic/mobile deployment of technologies should be assessed.

WP7 recommends adding the following points to the strategic research agenda:

- WP7 will provide several prototypes of measuring / monitoring systems (up to TRL7) for some typical waste package types. The SRA includes the extended time (3 years) for demonstration of a fully functioning system at a working facility.
- A full commercial analysis should be performed using the results of this demonstration.

7 Summary

7.1 Key Takeaways

The pre-proposal preparations in 2019 gathered inputs from industry via IGD-TP and Nugenia (now SNETP), which lead to focusing the project on four specific waste streams having highest urgency and importance from many Member States. These topics were also identified as areas where co-financing investment could be obtained for the consortium partners in-line with the joint program expectations. The identified gaps were also in accordance with topics identified in existing SRAs of EURAD and Nugenia and identified in JOPRAD. Later in-session polling during webinars of spring 2021 also reinforced that the focus topics were in-line with the audiences’ priorities.

The more comprehensive second phase Gap Analysis conducted over the first eight months of the PREDIS project has provided further insights to the industry and other end-users needs, challenges and priorities. A variety of methods were successfully applied to gain insight from a wider group of interested stakeholders. There was a high level of engagement and reach, worldwide, especially with the free live public webinars. In general, the Gap Analysis has shown that the scope of the PREDIS project is accurate, aligning with the most urgent topics for technical RD&D focus and investment, benefiting a wide number of Member States. The weighting between the four work packages and their relevant tasks was supported. Based on the Gap Analysis, minor re-tailoring or adjustments of the technical scope can be implemented to the existing PREDIS work packages and tasks.

Of the gaps identified on the basis of the defined objectives (Chapter 3) and processes (Chapters 4 and 5) outlined above, most (58 %) are already in the scope of the PREDIS technical work packages. Another portion of topics can be considered for inclusion by modification of the existing work package tasks. More specifically:

- **77** gap topics/issues were categorised as being **already in-scope** of the PREDIS project,
- **14** gap topics/issues were categorised as being **not in-scope, but could be** relevant to the PREDIS project,
- **34** gap topics/issues were categorised as being **not in-scope and can’t be, but could be promoted to the SRA** of the PREDIS project,
- **7** gap topics/issues were categorised as being **not in-scope and shouldn’t be** considered further by the PREDIS project.

It can be concluded that the project was originally well-designed based on the steps taken during the background preparation phase (Chapter 3). Only 10% of the gap analysis identified topics are well outside the scope of PREDIS, yet all gap analysis topics/issues can be considered for inclusion to the future Strategic Research Agenda.

7.2 Actions and Recommendations

The PREDIS Management Team expects that the majority of outcomes from the Gap Analysis (Chapter 6) will be accounted for in the update of the Description of Action, with regard to the RD&D activities of the tasks within the different work packages 4-7. Such adjustments may require re-adjustment of work effort and budget between tasks and partners. These will be described during the first periodic reporting (at Month 12, September 2021) to the European Commission. Overall, the allocation of total budget per work package (of roughly 20% of the total project budget to each WP4-7) is not expected to vary based on the second phase gap analysis outcomes. After the first-year review and feedback by the European Commission, the Management Team will provide a revised Description of Action by Month 18 (Milestone M3, by February 2022). Many of the topics that are flagged in the Gap Analysis can also be integrated to the future Strategic Research Agenda to be produced by PREDIS as a public Deliverable D2.4 due at Month 44 (April 2024).

APPENDIX 1: AGENDA FOR TA5 SESSION OF THE NUGENIA FORUM

Date: Friday March 15, 2019, at 14.00-17.00

Place: Nugenia Forum, Cite Internationale Universitaire de Paris, Paris, France. +Skype for Business

Invited: TA5 members, EURAD-Science, SHARE-Decommissioning, interested parties

Objective: EURATOM call NFRP-9 (decommissioning) and NFRP-10 (predisposal radwaste) preparations

14.00 **OPENING, objectives, meeting procedures** – Anthony Banford (chairperson, NNL)

14.10 **NFRP09 - DECOMMISSIONING**

14.10 IT-tools:
- 01 CEA (Christine) – 3D digitally enhanced decommissioning (3 min)
- 02 VTT (Erika) digital twins (1 min)
- DISCUSSION (5 min)

14.20 Characterisation
- 03 HZDR (T) – Combining calculations & experimental determination of inventory (3 min)
- 04 FMTC (Laurynas) – C-14 measuring prototype (1 min)
- 05 VTT (Erika) – Optical in-situ characterisation (1 min)
- DISCUSSION (5 min)

14.30 Decontamination
- 06 CVUT (Jan) – Advanced methods (3 min)
- 07 NNL (Matt) – Novel methods (1 min)
- DISCUSSION (5 min)

14.40 Dismantling technologies
- 08 EDF (Nicolas) – Graphite retrieval (presented 14.3 session already)
- 09 ONET (Julien) – laser cutting technologies (3 min)
- 10 NNL (Matt) – robotics (3 min)
- 11 NNL (Matti) - PPE for people protection (3 min)
- 11b GSL (Dan) – End state (3 min)
- DISCUSSION (5 min)

15.00 **NFRP10 - HORIZONTAL ACTIVITIES**
- 12 CVRez (Lumir) - Preliminary waste acceptance criteria (3 min)
- 13 UJVRez (Josef) – Management of legacy wastes (3 min)
- 14 FMTC (Laurynas) – Waste management for wastes lacking solutions (3 min)
- 15 NCSRD (Savidou) – Treatment of small inventories (3 min)
- DISCUSSIOIN (5 min)

15.20 *COFFEE BREAK*

15.30 NFRP10- RADWASTE PRE-DISPOSAL ACTIVITIES

15.30 Thermal Conditioning

16 GSL (Dan) – Alternative waste conditioning and treatment (3 min)
17 SCK-CEN (Christophe) – Chemical stability of slabs - plasma torch treatment (3 min)
18 CVR (Jan) – New types of matrices – stabilisation, vaporisation, combustion (3 min)
19 RATEN (Crina/video) – Oxidative method for spent ion exchange resins (1 min)
DISCUSSION (5 min)

15.45 Graphite & Metallic waste handling

20 SCK-CEN (Christophe) – Irradiated graphite conditioning and treatment (3 min)
21 FZJulich (G) – Handling metallic waste and irradiated graphite (1 min)
22 EDF (Jeremy) – Minimisation and recycling very low activity metallic materials (1 min)
23-24 RATEN (Crina) – Irradiated graphite & aluminium conditioning and treatment (1 min)
DISCUSSION (5 min)

16.00 Waste Immobilisation

25 CEA (Frederic) – Innovation conditioning methods and technologies (3 min)
26 VTT (Erika) – Geopolymers for immobilisation (1 min)
26b SIPT (Sergey Kharkov) – Waste treatment
27 SCK-CEN (Christophe) – Durability of geopolymers (1 min)
DISCUSSION (5 min)

16.15 Monitoring of pre-disposal packages

28 PSI (Sergey) – Modelling & experiments on cemented material degradation (3m)
29 GSL (Dan) – Monitoring waste package performance in long-term storage (3 min)
30 SCK-CEN (Christophe) – Characterisation of radiological content (3 min)
DISCUSSION (5 min)

16.30 WAY FORWARD DISCUSSION (lead by Anthony & Christine)

Knowledge Management Activities
Consortium building, joint-program (EURAD links)
Schedule/next steps towards submission

17.00 ADJOURN

APPENDIX 2: PRE-PROJECT SURVEY

Review template #1 for possible Technical Work packages to NFRP-10 Proposal on Pre-disposal Radioactive Waste Management call - May 2019

Please return this survey to Erika Holt (erika.holt@vtt.fi) and Maria Oksa (maria.oksa@vtt.fi) by Thursday May 9.

Organisation

- *Please give the contact details of your organisation (including email address of contact person who completed or coordinated this review)*
- *Indicate in which category your organisation falls:*
  - ☐ *waste owner/producer,*
  - ☐ *waste management organisation,*
  - ☐ *regulatory body/TSO or*
  - ☐ *other* _____

Waste type prioritisation

The NFRP-10 project will target in its Technical Work Packages several waste types. Please indicate in the following table: 1) which waste types are relevant for (i.e., produced and/or managed by) your organisation (mark with an X); 2) which waste type (relevant for your organisation, and therefore marked by an X in the previous column) should receive highest priority (please rank from 1 (high) to 6 (low) from highest to lowest priority, respectively). There is an additional column for commenting. Please use this column if you want to specify certain attention points for a waste type.

Waste Type		Relevant?	Priority	Comment
Liquid organic waste				
Solid organic waste	bituminised waste, polymerised waste;			
	resins			
	consumables, others			
Metallic L&ILW	Reactive metals			
	Contaminated steel			
	Activated steel			
	Others			
Graphite				
Cemented waste				

Evaluation per Work Package

Please give your assessment per Work Package on :

- *The clarity, pertinence and outlook on the achievability of the stated objectives (based on your insights) of the WP;*
- *The innovative character of the work proposed, and if the WP would contribute sufficiently to the increase of scientific and technical knowledge (beyond state of the art);*

- *The relevance of the end results for your organisation, the share of your inventory that can benefit from the WP results, and the added value that is created by the WP;*
- *An estimation at what point in the future do you hope to gain benefit from the outcome of the WP and how;*
- *Other needs you think are missing if any.*

(*If a particular WP is not relevant for your organisation, based on the table above, there is no need to answer these questions).*

Target length per WP assessment is a few bullets to half page (short, concise is appreciated).

Work package 1: Treatment and recycling of metallic materials and waste
Work package 2: Graphite materials treatment and conditioning
Work package 3: Liquid organic waste
Work package 4: Solid organic waste
Work package 5: Cemented waste and packages
Work package 6: Qualification and acceptance of waste

Involvement as End User

Please indicate by answering the following questions:

- *If your organisation wants to be involved in the project as end-user and specify on which WP (indication only, exact role can be defined later)*
- *If your organisation wants to be involved in the project as (active) participant or partner*
- *If you consider that your organisation may want to (co-)finance certain Work Packages and/or participants within the project (and if so, which Work Packages)*
- *If you would like to be removed from the mailing list, or have a different person in your organisation who should be included in the future.*

Additional comments

Feel free to provide additional comments, if appropriate

APPENDIX 3: SCOPE OF PREDIS WORK PACKAGES 4-7

WP4 Metallic material treatment and conditioning
Total effort: 534 PM (person-months), among 23 partners
Lead: Bernd GRAMBOW, IMT-Atlantique (France)

Tasks (lead partner):
- T4.1 WP management (IMTA)
- T4.2 Defining Europe-wide Needs and Opportunities for Management of Metallic Waste Streams (GSL)
- T4.3 Development and optimisation of decontamination processes (IMTA)
- T4.4 Optimisation of metallic waste characterisation and procedures for waste minimisation and recycling (NCSRD)
- T4.5 Encapsulation of reactive metals in magnesium phosphate cement-based matrices (CNRS)
- T4.6 Dissemination (IMTA)

Innovations:
- Develop innovative conditioning matrices for reactive metallic wastes.
- Develop innovative and optimised characterisation techniques for metallic wastes.
- Demonstrate innovative techniques to decontaminate metallic wastes to quantify the efficiency of decontamination processes and allow more effective application of the waste hierarchy.
- Develop treatment techniques for secondary waste streams after decontamination.

WP5 Liquid Organic waste treatment and conditioning
Total effort = 618 PM, among 21 partners
Lead: Maxime Fournier, CEA (France)

Tasks (lead partner):
- Task 5.1 WP5 Management (CEA)
- Task 5.2 Collection & review of waste, regulatory, scientific & technical data (GSL)
- Task 5.3 Study of direct conditioning process (RATEN & SOGIN)
- Task 5.4 Study of conditioning matrix performances (ECL & USFD)
- Task 5.5 Preliminary technical, economic and environmental analysis (GSL)
- Task 5.6 Implementation & dissemination (UNIPI)

Innovations:
- Study of innovative materials (geopolymers) and their interactions with ROLW
- Development of direct conditioning solutions for RLOW based on geopolymer from TRL3 to TRL6 including validation tests with real waste and feasibility scale-up tests.
- Optimisation of geopolymers options and formulations to optimise ROLW encapsulation, especially incorporation rates and matrix performance.
- Process robustness regarding waste, raw materials and process variability including study definition and execution of non-standard tests to verify the stability and durability of the final waste form.
- Disposability assessment from the study of matrix performances and long-term behavior including “technical standard tests” related to WAC when available and scientific approaches for deeper physico-chemical understanding including the development of methodologies to evaluate parameters important for disposability assessment.

WP6 Solid Organic waste treatment and conditioning
Total: effort509 PM, among 14 partners.
Lead: Thierry Mennecart, SCK CEN (Belgium)

Tasks (lead partner):
- Task 6.1 Work package management (SCK CEN)
- Task 6.2 Database on solid organic waste forms and their final state and value assessment analysis (GSL)
- Task 6.3 Thermal treatment of the radioactive waste forms and characterisation of the treated / conditioned wastes (CEA)

- Task 6.4 Immobilisation of the treat wastes by geopolymer or cement-based materials encapsulation or by molten glass coating (CVRez)
- Task 6.5 Densification (USFD)
- Task 6.6 Physico-chemical characterisation of conditioned waste form and stability testing (VTT)
- Task 6.7 Economic and Environment impact - Implementation (GSL)
- Task 6.8 Dissemination and Reporting (SCK CEN)

Innovations:

- Closing the cycle for treatment of solid organic wastes by proposing, developing, testing and verifying suitable matrices for conditioning of residues and secondary wastes stemming from (thermal) treatment options (like those investigated within the earlier THERAMIN project).
- Development of geopolymers as alternative binder material to ordinary cement-based systems for conditioning of residues and secondary wastes.
- Demonstrate robustness of full treatment cycle for selected solid organic waste streams.
- Assessment of full treatment cycle in terms of technology and economical assessment, achieved volume reduction factor, final conditioned matrix performance and related WAC for different primary waste stream physico-chemical characteristics.

WP7 Cemented waste handling and pre-disposal storage
Total effort: 408 PM, among 17 partners
Lead: Ernst Niederleithinger, BAM (Germany)
Tasks (lead partner):

- Task 7.1 WP management (BAM)
- Task 7.2 State of the art in packaging, storage, and monitoring of cemented wastes (GSL)
- Task 7.3 Innovative integrity testing and monitoring techniques (BAM)
- Task 7.4 Digital Twin (PSI)
- Task 7.5 Data handling, processing and fusion (VTT)
- Task 7.6 Demonstration and implementation of monitoring, maintenance, and automation/digitalisation techniques (Orano)
- Task 7.7 Dissemination and Reporting (GSL)

Innovations:

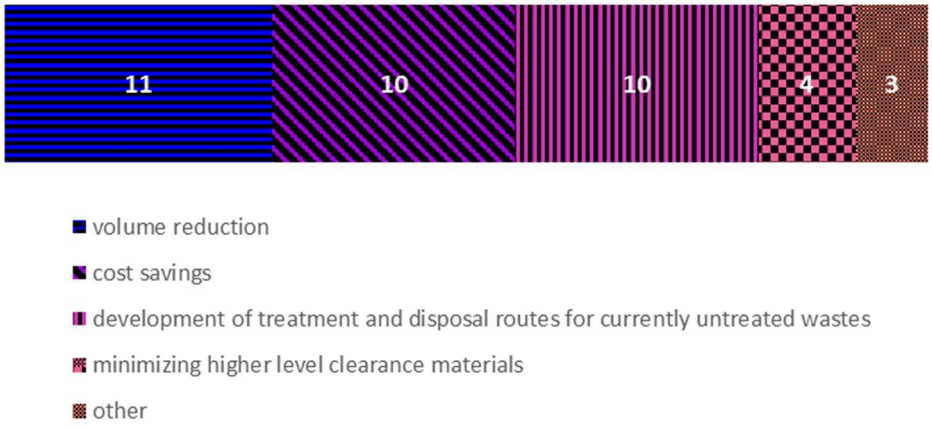
- Innovative NDE tools for evaluation of package integrity, including, but not limited to visual methods, muon tomography and ultrasonic techniques
- Innovative sensor technologies for instrumented packages, including, but not limited to fiber optical techniques and methods for wireless power supply and data transmission
- An approach for developing and maintaining digital twins of packages, including a package evolution model based on inventory data, chemical and mineralogical characterisation data, data from chemical modelling, and monitoring data
- Application of machine-learning algorithms, trained on digital datasets, to produce a fast and accurate description of the geochemical evolution and the geo- and thermo-mechanical integrity of radioactive waste packages during pre-disposal
- A digital twin of a radioactive waste package based on machine-learning algorithms that can offer advanced information for waste package inspection protocols and, thus, contribute to safety of storage facilities
- Large digital database to train the machine-learning algorithms
- A decision framework model that is based on existing knowledge, data from measurements and predictions from digital twins
- Advancement of the overall TRL for data handling, processing and fusion in the context of intermediate radioactive waste storage from 4 to 6
- Reports on treatment options for existing packages, potential improvements in package design and recommendations for store automation concepts

APPENDIX 4: WP4-RELATED GAP ANALYSIS RESULTS

EUG On-line Feedback Survey

Note: Only those questions with gap analysis implications are included here; question numbers correspond exactly to those in the original survey.

Question 13: What are the primary interests of your organisation related to metallic waste treatment?



Question 13a: If other, please specify

Topic	Categorisation	Notes
minimising surface/mass and gas production	already in-scope	
decommissioning wastes	already in-scope	
characterisation of mixed, unknown intermediate level wastes	already in-scope	

Question 16: Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?

Topic	Categorisation	Notes
establishing the trade-off between reduction of gas generation and cost; providing a sound method for decision making	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
characterisation of heterogeneous items or containers	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
extraction of metals from mixed metal/non-metal wastes; ILW/LLW separation	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
alpha contaminated aluminium and beryllium matrices for which to date no long-term management scenario is defined yet	already in-scope	
decontamination; free release measurements after decontamination	already in-scope	
conditioning of metallic actinide waste forms	already in-scope	
decontamination of small diameter piping	already in-scope	
disposal of reactive metals	not (entirely) in-scope and can't be, but could be promoted to the SRA	WP4 addresses conditioning of Al and Be wastes but not disposal per se
finding routes for cleared metal waste, e.g., national limits permit release but scrap metal handlers refuse receipt	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
optimisation of cement formulations with respect to environmentally toxic substances; workability during cementation	already in-scope	
methods of solidification or grouting for metallic scrap waste which will have be disposed in DGR	already in-scope	
use of various binders for cementing LRW; effect of the characteristics of binders on the properties of cemented products	already in-scope	

Question 17: What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?

Topic	Categorisation	Notes
(effective) characterisation of surfaces or surface/mass ratios, e.g., during decommissioning	already in-scope	
coupling gamma spectrometry and tomography	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
cementation	already in-scope	
demonstrating pre-condition information and final package information regarding difficult or even impossible to measure nuclides; efficient metal type recognition in hot cell-conditions; decontamination of ILW metals and characterisation for discard	not (entirely) in-scope and can't be, but could be promoted to the SRA	WP4 addresses measuring DTM radionuclides under some conditions
decontamination and super-pressing	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
disposal routes for reactive metals (beryllium, aluminium)	not (entirely) in-scope and can't be, but could be promoted to the SRA	WP4 addresses conditioning of Al and Be wastes but not disposal per se
handling of large, highly active components; decontamination in harsh conditions	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP

WP4 Technical Webinar

WP4 - Categorised Webinar Takeaways

Topic/Issue	Categorisation	Notes
management of secondary wastes from chemical decontamination	already in-scope	
reduction in costs of metallic waste management	already in-scope	
radiological characterisation methods	already in-scope	
gamma camera technology	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
uncertainty reduction in neutron activation calculations	not in-scope, but could be	such validation of the calculations can be performed without extra budget because it would be an extension of the MCNPX simulations which are foreseen in the budget
understanding hydrogen production in the geologic disposal of metallic wastes	already in-scope	
waste loading in conditioning matrices for metallic wastes	not in-scope, but could be	
performance of conditioning matrices for metallic wastes	already in-scope	
reduction in costs for magnesium phosphate encapsulation	already in-scope	
mobile waste treatment	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
segregation and characterisation of metallic wastes	already in-scope	
recycling and reuse in metallic waste management	already in-scope	

Summary Table from WP4 Internal Gap Analysis Report

WP4 Internal Gap Analysis Issue Categorisation

No.	Identified Gap	Source	Classification	Phase	Priority	Technology Level	PREDIS Relevant
1	optimisation of chemical decontamination	literature review, interaction with end users, technical webinar, project workshop	metallic waste	treatment (decontamination)	high	near	yes
2	management of secondary wastes	literature review, technical webinar, project workshop	metallic waste	treatment (decontamination) and conditioning	high	near	yes
3	mobile waste treatment	technical webinar, project workshop	all	treatment	medium	near	no
4	radiological characterisation and segregation	literature review	metallic waste	characterisation	high	near	yes
5	validation of neutron activation calculations	technical webinar	metallic waste	characterisation	high	partway	yes
6	validation of scaling factors	end users	metallic waste	characterisation	high	partway	yes
7	gamma camera technology	end users	metallic waste	characterisation	medium	partway	no

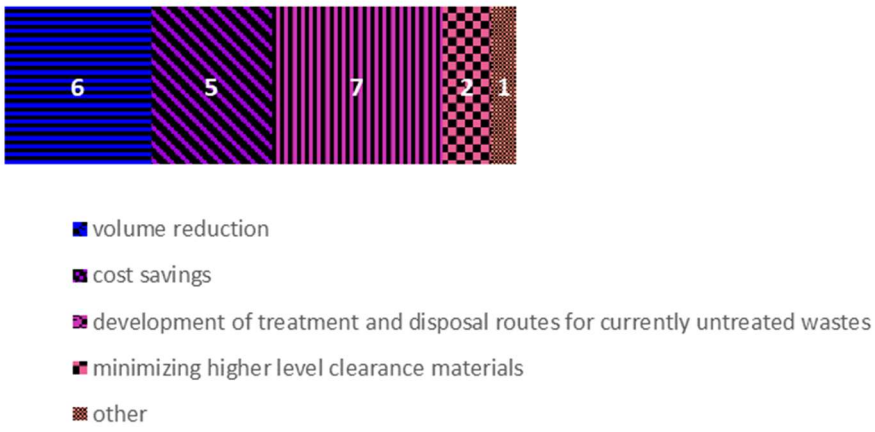
8	optimisation of the MPC formulation	literature review	metallic waste	conditioning	high	near	yes
9	characterisation of the MPC	literature review, technical webinar, project workshop	metallic waste	conditioning	high	near	yes
10	optimisation of the MPC cost	end users	metallic waste	conditioning	high	partway	yes
11	study of the Al and Be reactivity in MPC, determination of the hydrogen volume produced by corrosion in the package.	literature review, end users, technical webinar	metallic waste	conditioning	high	near	yes

APPENDIX 5: WP5-RELATED GAP ANALYSIS RESULTS

EUG On-line Feedback Survey

Note: Only those questions with gap analysis implications are included here; question numbers correspond exactly to those in the survey.

Question 24: What are the primary interests of your organisation related to liquid organic waste treatment?



Question 24a: If other, please specify

Topic	Categorisation	Notes
clearance of very lightly contaminated liquids	already in-scope	

Question 25: Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?

Topic	Categorisation	Notes
demonstration of the durability of waste forms from new conditioning methods	already in-scope	
development of LOW immobilisation matrices in cases where incineration is not available	already in-scope	
issues related to WAC and complexing agents	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP
alpha measurement on liquids (oils); solutions for fluorinated oil (from high vacuum systems); organic waste with unacceptably high levels of Cl and F to meet current waste acceptance criteria	not in-scope and can't be, but could be promoted to the SRA	the work of this WP is focused on highest priority and largest volume RLOW waste streams
treatment of ^{3}H and ^{14}C containing organic solutions;	not in-scope and can't be, but could be promoted to the SRA	the work of this WP is focused on highest priority and largest volume RLOW waste streams

treatment of biological wastes (e.g., carcasses)		
optimisation of cement formulations with respect to environmentally toxic substances; workability during cementation	already in-scope	
use of various binders for cementing LRW; effect of the characteristics of binders on the properties of cemented products	already in-scope	

Question 26: What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?

Topic	Categorisation	Notes
incineration and cement immobilisation of products	not in-scope and can't be, but could be promoted to the SRA	completely out of scope for WP5 which focuses on direct immobilisation of LOWs, but could be promoted to the SRA for future efforts in liquid organic waste conditioning for problematic wastes, i.e., those not amenable or approved for direct conditioning
radiological characterisation (alpha measurements); Cl and F removal from organic waste streams; development of implementable treatment and disposal routes for organic waste streams	not in-scope and can't be, but could be promoted to the SRA	completely out of scope for WP5 which focuses on direct immobilisation of LOWs, but could be promoted to the SRA for future efforts in liquid organic waste conditioning for problematic wastes, i.e., those not amenable or approved for direct conditioning
cost effective treatment technologies for low volume organic waste streams	already in-scope	

Question 27: Does your organisation have any radioactive liquid organic wastes that could benefit from direct conditioning in a geopolymer-type matrix? If yes, please specify.

Topic	Categorisation	Notes
resins (mentioned repeatedly) and sludges	not in-scope, and shouldn't be	completely out of scope for WP5 which focuses on LOWs; see WP6
oils, scintillation liquids, organic liquids from steam generator cleaning	already in-scope	

Question 28: Is your organisation facing waste acceptance criteria issues for liquid organic wastes or geopolymers containing liquid organics? If yes, please specify.

Topic	Categorisation	Notes
quantity limits on LOW in cement matrices	already in-scope	
incomplete WAC	not in-scope and can't be, but could be promoted to the SRA	WAC development is outside the scope of WP5; information regarding conditioning matrix performances and behaviour in relation with certain disposal, transport and prolonged storage requirements and specifications will be obtained
water soluble chlorides not allowed in treated or conditioned wastes	not in-scope and can't be, but could be promoted to the SRA	the work of this WP is focused on highest priority and largest volume RLOW waste streams
limiting chelating and complexing agent content, determination of organic/inorganic ratio for ^{14}C	already in-scope	this issue will be examined in the formulation of matrices designed to limit surfactant content

WP5 Technical Webinar

WP5 - Categorised Webinar Takeaways

Topic/Issue	Categorisation	Notes
demonstration of geopolymer conditioned waste compliance with waste acceptance criteria	already in-scope	can be done when WAC are available, which is not frequent
analysis of natural analogue evidence in WAC compliance demonstration for geopolymer conditioned wastes	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
immobilisation of liquids in geopolymer matrices over disposal-relevant timescales	already in-scope	
evolution of geopolymer structures (e.g., secondary phase formation, changes in porosity) and entrapped liquids over time	already in-scope	
the use of geopolymers for conditioning reactive metal wastes	not in-scope and can't be, but could be promoted to the SRA	completely out of scope for WP5 which focuses on LOWs, but could be promoted to the SRA for future efforts in metallic waste conditioning
application of geopolymers to cases or conditions where established cements do not perform suitably	already in-scope	
establishing geopolymer material standards (for use in waste conditioning)	already in-scope	
performance of geopolymers compared to Nochar products	already in-scope	
Increase of waste loadings in geopolymers in order to reduce the volume of material to be disposed.	already in-scope	
Security of supply of raw materials for geopolymers manufacturing through the use of locally sourced raw materials	already in-scope	

Summary Table from WP5 Internal Gap Analysis Report

WP5 Internal Gap Analysis Issue Categorisation

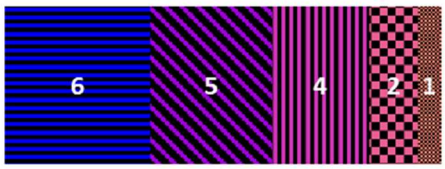
No.	Identified Gap	Source	Classification	Phase	Priority	Technology Level	PREDIS Relevant
1	comparison of geopolymer conditioning to other/existing solutions	waste generators	liquid organic waste	conditioning	high	near	yes
2	optimisation of waste loading	waste generators	liquid organic waste	conditioning	high	partway	yes
3	applicability of conditioning methods	waste generators	liquid organic waste	conditioning	high	partway	yes
4	upscaling of conditioning methods	waste generators	liquid organic waste	conditioning	medium	partway	yes
5	use of locally sourced formulation materials	internal WP	liquid organic waste	conditioning	medium	partway	yes
6	use of recycled formulation materials	internal WP	liquid organic waste	conditioning	medium	far	yes
7	wasteform performance	WMOs	liquid organic waste	storage, disposal	high	partway	yes

APPENDIX 6: WP6-RELATED GAP ANALYSIS RESULTS

EUG On-line Feedback Survey

Note: Only those questions with gap analysis implications are included here; question numbers correspond exactly to those in the survey.

Question 31: What are the primary interests of your organisation related to solid organic waste treatment?



- volume reduction
- cost savings
- development of treatment and disposal routes for currently untreated wastes
- minimizing higher level clearance materials
- other

Question 31a: If other, please specify

Topic	Categorisation	Notes
waste acceptance	not in-scope and can't be, but could be promoted to the SRA	WAC development or specific compliance is outside the scope of WP6; information regarding waste form performance and behaviour will be obtained

Question 32: Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?

Topic	Categorisation	Notes
increase the amount of resins per package	already in-scope	for resins amenable to the degradation processes under development in WP6, optimised loading of the waste residues in immobilisation matrices will be investigated
WAC relating to complexing agents	not in-scope and can't be, but could be promoted to the SRA	WAC development or specific compliance is outside the scope of WP6; information regarding waste form performance and behaviour will be obtained
basis for limiting organic material content in waste packages as part of waste acceptance criteria	not in-scope, but could be	treatment schemes under development in WP6 should lead to complete decomposition of organic material; product residues could be analysed for organic compounds

optimisation of cement formulations with respect to environmentally toxic substances; workability during cementation	already in-scope	
use of various binders for cementing LRW; effect of the characteristics of binders on the properties of cemented products	already in-scope	

Question 33: What methods, processes, technologies and/or demonstrations would be most useful for your organisation from this Work Package?

Topic	Categorisation	Notes
incorporation of resins in geopolymers	not in-scope and shouldn't be	direct conditioning is not the aim of WP6; the primary focus is volume reduction by thermal or other degradation treatment
techniques which have a broad applicability in terms of acceptable waste streams as the sometimes relatively small volumes of separate waste streams do not justify the investigation and development of a separate scheme for each	already in-scope	

Question 35: Is your organisation facing waste acceptance criteria issues for solid organic wastes or geopolymers containing solid organic wastes? If yes, please specify.

Topic	Categorisation	Notes
further development of WAC	not in-scope and can't be, but could be promoted to the SRA	WAC development is outside the scope of WP6; information regarding waste form performance and behaviour will be obtained
WAC for disposal incomplete or unavailable	not in-scope and can't be, but could be promoted to the SRA	WAC development is outside the scope of WP6; information regarding waste form performance and behaviour will be obtained

WP6 Technical Webinar

WP6 - Categorised Webinar Takeaways

Topic/Issue	Categorisation	Notes
electrochemical methods for the degradation of resins	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
optimisation of incineration and geopolymer immobilisation techniques for IERs	already in-scope (task 6.4)	
in-drum pyrolysis of cellulosic waste	already in-scope	
in-drum pyrolysis of bituminised waste	not in-scope, but (maybe) could be	pyrolysis of bituminised waste is of current interest, but those EUG members managing such waste made the strategic decision to focus on cellulosic wastes; it is uncertain whether the processes being tested in PREDIS would be suitable for processing this waste, however, WP6 is looking to analyse thermally treated products from a range of sources including incineration and plasma treatment (in Task 6.3), and as plasma treatment was identified in THERAMIN as a good candidate for treating bitumen, WP6 could look to analyse existing samples of plasma glass from treated bitumen waste, otherwise this topic could be promoted to the SRA
sustainability and wider environmental impact of solid organic waste treatment and conditioning	already in-scope (task 6.7)	
volume reduction of solid organic waste	already in-scope (task 6.2 & 6.7)	
cost control and reduction for solid organic waste treatment and conditioning	already in-scope (task 6.7)	
fate of heavy metals in solid organic waste treatment and conditioning	not in-scope and shouldn't be	if heavy metals refer to U and Pu

harmonisation of treatment and conditioning methods with waste acceptance criteria	not in-scope, but could be	to the extent that WAC are available, they are generally not (exactly) the same from one country to another; outcomes of WP6 regarding waste form performance could be compared to various WAC by consortium partners in their national context
waste loading of geopolymer matrices for solid organic wastes	already in-scope (task 6.4)	
viability of treatment technologies over a wide range of solid organic waste streams	already in-scope (task 6.2)	
improvement of thermal plasma torch lifetimes	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
solid organic waste characterisation	not in-scope and shouldn't be	characterisation, especially of legacy wastes, is not the aim of WP6 and this topic is already included in CHANCE and EURAD-Routes

Summary Table from WP6 Internal Gap Analysis Report

WP6 Internal Gap Analysis Issue Categorisation

No.	Identified Gap	Source	Classification	Phase	Priority	Technology Level	PREDIS Relevant
1	radioactive solid organic waste inventories	internal WP	solid organic waste	characterisation	high	partway	yes (as input data)
2	identification of the most suitable / relevant thermal treatment for RSOWs	end user needs (proposal preparation)	solid organic waste	treatment	high	partway	yes
3	selection of the most suitable binders / matrices for the immobilisation of thermally treated waste	THERAMIN final report; EU review	solid organic waste	conditioning	high	partway	yes
4	durability and stability evaluation of conditioned wastes under disposal conditions	end user review, 1st workshop, technical webinar	solid organic waste	disposal	high	partway	yes (under reference conditions)
5	computational tool for designing immobilisation matrices and evaluating performance	end user needs (proposal preparation)	solid organic waste	conditioning, packaging, storage, disposal	medium	far	yes
6	environmental and economic impact of predisposal management scheme	end user review	solid organic waste	treatment, conditioning, packaging, storage	medium	partway	yes
8	characterisation of legacy wastes	1st workshop, technical webinar	solid organic waste	characterisation	high	partway	yes

APPENDIX 7: WP7-RELATED GAP ANALYSIS RESULTS

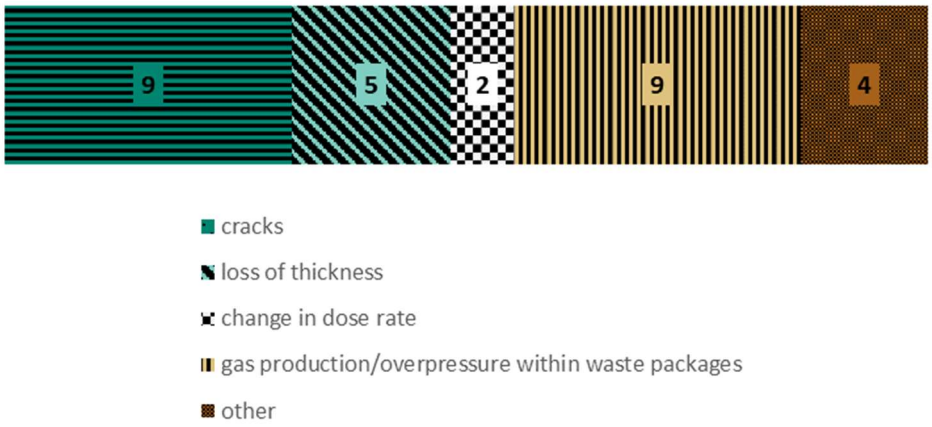
EUG On-line Feedback Survey

Note: Only those questions with gap analysis implications are included here; question numbers correspond exactly to those in the survey.

Question 38: Are there any challenges/needs your organisation would like specifically to be addressed in this Work Package or any specific topics/ideas/gaps that were missed?

Topic	Categorisation	Notes
pH and aging effects	not in-scope, but could be	
NDT for toxic chemical species	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal for this WP; the necessary competence to carry out such work was not assembled within the consortium
long term predictions/confirmation on stabilising measures, e.g., adding extra cement to neutralise acid build-ups.	already in-scope	
NDT for physico-chemical properties, imaging and radiological characterisation; WAC overview in other countries; information on issues/detrimental chemical reactions encountered with cemented waste packages	not in-scope, but could be	
NDT to investigate heterogeneous waste forms inside cemented packages; sampling techniques; applicability to wide range of waste forms, e.g., ashes, resins and mixed scrap & trash	not in-scope, but could be	

Question 40: What are the main topics, connected with cement waste package degradation that your organisation would like to see detected and monitored as a priority by instrumentation and controls, and be considered during demonstration tests?



Question 40a: If other, please specify.

Topic	Categorisation	Notes
ASR and DEF (expansion processes)	already in-scope	
leachability (multiple mentions), compressive strength, long-term stability	not in-scope, but could be	
chemical reactions (ASR)	already in-scope	

Question 41: Which durability performance indicators are most relevant?

Topic	Categorisation	Notes
post closure pH evolution, avoidance of adverse chemical reactions; pressure resistance / strength for interim storage	not in-scope, but could be	
changes in compressive strength, leachability, mechanical, microbial and radiation stability	not in-scope, but could be	
indicators that conditioning requirements are met	already in-scope	
techniques for visual monitoring and analysis of concrete	already in-scope	
durability and chemical reaction information on samples aged for one year at 38 °C including microscopic data	not in-scope and (likely) can't be, but could be promoted to the SRA	collection of this information was not planned or provided for in the original project proposal; to the extent it is available elsewhere it could possibly be used as input to digital twin simulation development depending on progress made there
integrity of outer metal barrel and inner cement mantle	already in-scope	

leaching and hardness	not in-scope, but could be	
durability indicators relating to final disposal	not in-scope, but could be	

Question 46: What measurements or analyses are missing from the portfolio of available non-destructive evaluation techniques / monitoring technologies / instrumentation?

Topic	Categorisation	Notes
standoff alpha detection	not in-scope and shouldn't be	covered elsewhere
active and passive neutron detection (scanner, neutronography), transmission and emission tomography, angular gamma scanning	not in-scope and shouldn't be	covered elsewhere
X-ray for small volumes of cemented waste content	not in-scope and shouldn't be	covered elsewhere
radiological content of waste packages including the more difficult to measure radionuclides	not in-scope and shouldn't be	covered elsewhere
imaging of cracks if present at the top surface; demonstration of absence of ASR or other detrimental chemical reactions	already in-scope	
tomographic techniques, gamma camera, neutron spectroscopy (passive or active); densitometry, detection of out gassing, ultrasonic or radar techniques	already in-scope	

WP7 Technical Webinar

WP7 - Categorised Webinar Takeaways

Topic/Issue	Categorisation	Notes
monitoring of waste package degradation	already in-scope	
application of new developments in monitoring and characterisation technologies to WAC issues	already in-scope	
monitoring of internal waste package pressure	not in-scope, but could be	
cost benefit analysis of implementing new technologies	already in-scope	
efficiency of introducing new monitoring technologies into existing facilities versus designing and constructing new facilities	not in-scope and can't be, but could be promoted to the SRA	this topic was not planned or provided for in the original project proposal; the necessary competence to carry out such work was not assembled within the consortium
development of specific information on the capabilities of digital twin simulations for waste package monitoring and storage	already in-scope	
monitoring needs for short-term storage versus monitoring needs for long-term storage.	already in-scope	
development of resources, information, publications, good practices, training and knowledge transfer networks that can be used to improve organisational capabilities related to waste package monitoring and storage with emphasis on monitoring options that can be implemented today versus those that require ongoing R&D.	already in-scope	

Summary Table from WP7 Internal Gap Analysis Report

WP7 SOTA Report Gap Analysis Issue Categorisation

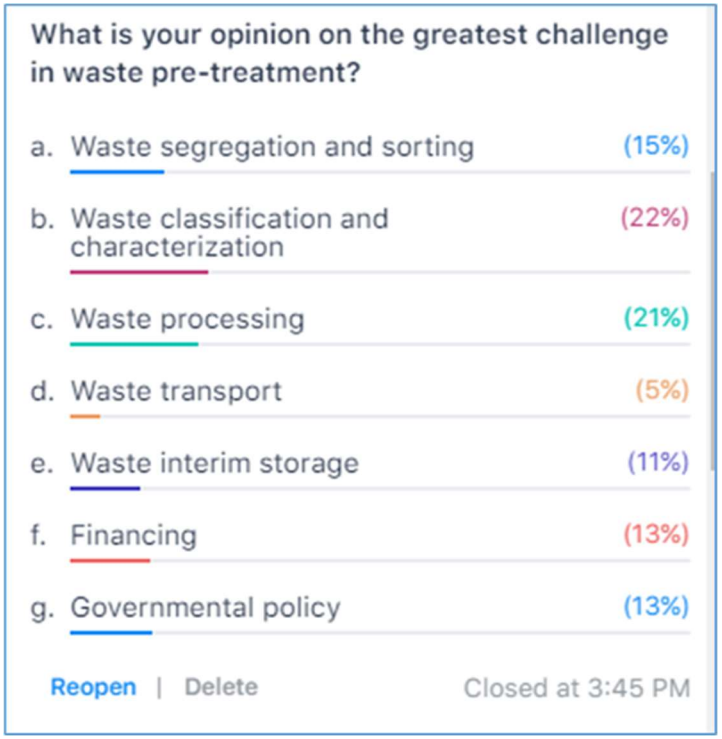
No.	Identified Gap	Source	Classification	Phase	Priority	Technology Level	PREDIS Relevant
1	monitoring internal pressure of waste packages	WP7 SOTA/ End User need	cement conditioned waste streams	storage	medium	partway	yes
2	monitoring variation of waste package dimensions	WP7 SOTA / End User need	cement conditioned waste streams	storage, transport	medium	near	yes
3	monitoring external and internal corrosion	WP7 SOTA / End User need	cement conditioned waste streams	storage, transport	high	partway	yes
4	monitoring degradation and cracks in cement matrices	WP7 SOTA / End User need	cement conditioned waste streams	storage	high	partway	yes
5	monitoring leakage	WP7 SOTA / End User need	cement conditioned waste streams	storage, transport	high	partway	relevant sensor technology already exists, could be integrated to open interface platform
6	waste package monitored data handling	WP7 SOTA / End User need	cement conditioned waste streams	storage	medium	partway	yes
7	monitoring fissile content	WP7 SOTA/End User need	cement conditioned waste streams	storage	low	partway	yes (using data from MICADO project)

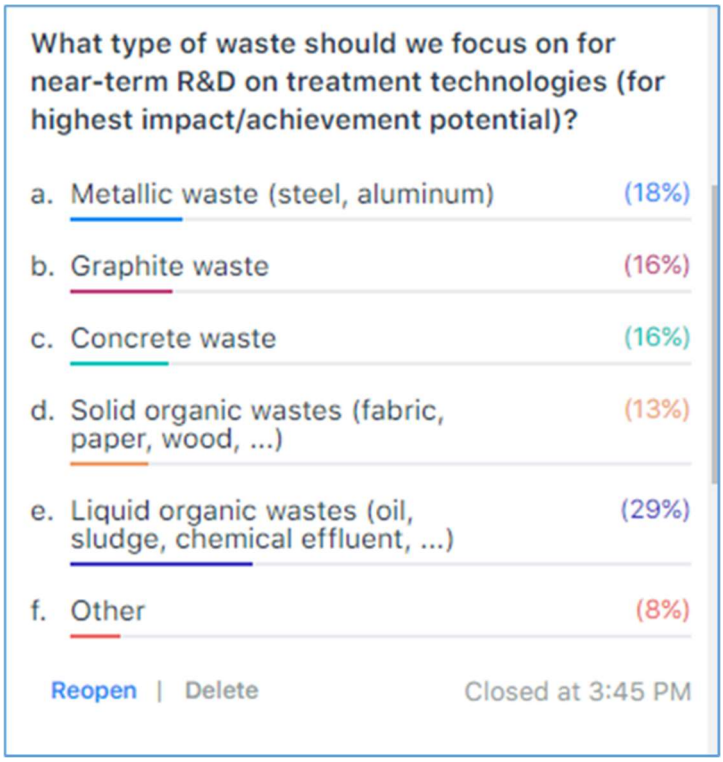
8	prediction of chemical reactions and gas generation	WP7 SOTA / End User need	cement conditioned waste streams	storage	medium	partway	yes
9	monitoring condensation	WP7 SOTA / End User need	cement conditioned waste streams	storage	low	partway	relevant sensor technology already exists, could be integrated to open interface platform
10	monitoring gas emissions	WP7 SOTA / End User need	cement conditioned waste streams	storage, transport	low	partway	yes (using data from CHANCE project)
11	monitoring dose rates	WP7 SOTA / End User need	cement conditioned waste streams	conditioning, storage, transport	low	partway	yes (using data from MICADO project)
12	monitoring internal wasteform conditions	WP7 SOTA / End User need	cement conditioned waste streams	conditioning, storage, transport	low	partway	yes
13	mobile monitoring systems	WP7 SOTA / End User need	cement conditioned waste streams	conditioning, storage, transport	medium	far	yes
14	characterisation of cemented legacy wastes for content and integrity	WP7 SOTA / End User need	cement conditioned waste streams	conditioning, storage	medium	partway	yes (for model validation)
15	establish qualitative links between wasteform chemical behaviour and package integrity	WP7 SOTA / End User need	cement conditioned waste streams	conditioning, storage	medium	partway	yes

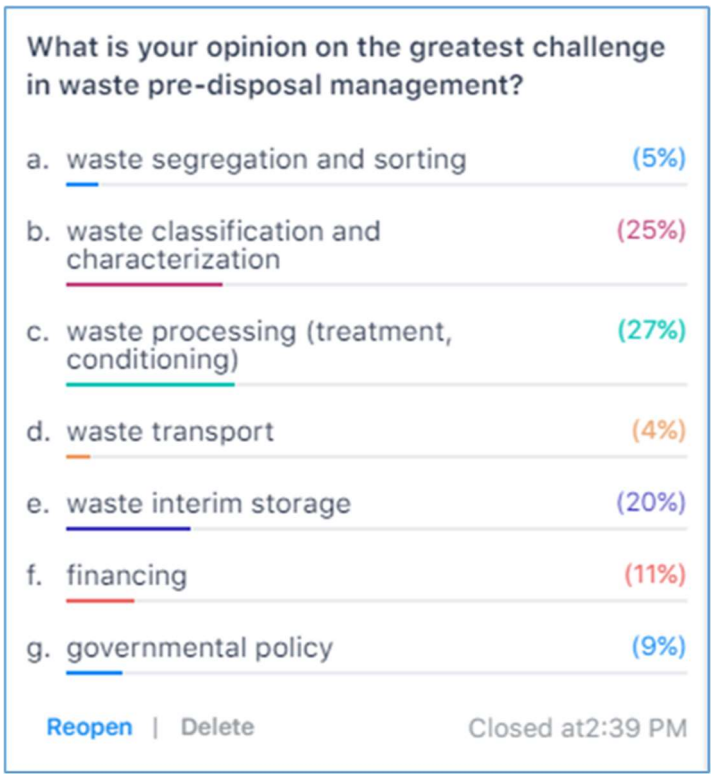
WP7 Internal Gap Analysis Issue Categorisation

No.	Identified Gap	Source	Classification	Phase	Priority	Technology Level	PREDIS Relevant
1	provide user-friendly tool for end-users to predict the behaviour of cemented waste packages during interim storage based upon initial content/composition to evaluate alternative packaging options and the effect of repackaging.	end user need	cement conditioned wastes	conditioning, storage	medium	partway	yes
2	define key performance indicators of waste package integrity that could be used to design the monitoring strategy and modelling approach	end user need	cement conditioned wastes	conditioning, storage	high	partway	yes

APPENDIX 8: LIVE-POLLING RESULTS, EURAD AND SNETP EVENTS






What is your opinion on the greatest challenge in waste pre-disposal management?
a. waste segregation and sorting (5%)
b. waste classification and characterization (25%)
c. waste processing (treatment, conditioning) (27%)
d. waste transport (4%)
e. waste interim storage (20%)
f. financing (11%)
g. governmental policy (9%)
Reopen | Delete
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What type of waste should we focus on for near-term R&D on treatment technologies (for highest impact/achievement potential)?
a. metallic waste (steel, aluminium ...) (17%)
b. graphite waste (10%)
c. concrete waste (14%)
d. solid organic wastes (fabric, paper, wood ...) (17%)
e. liquid organic wastes (oil, sludge, chemical effluent ...) (41%)
f. other (0%)
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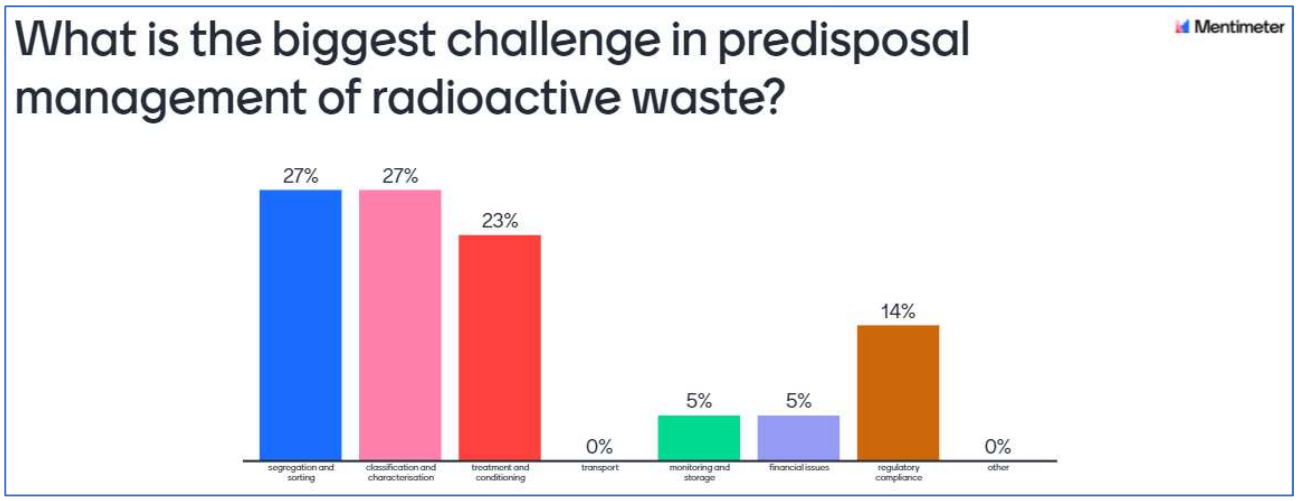
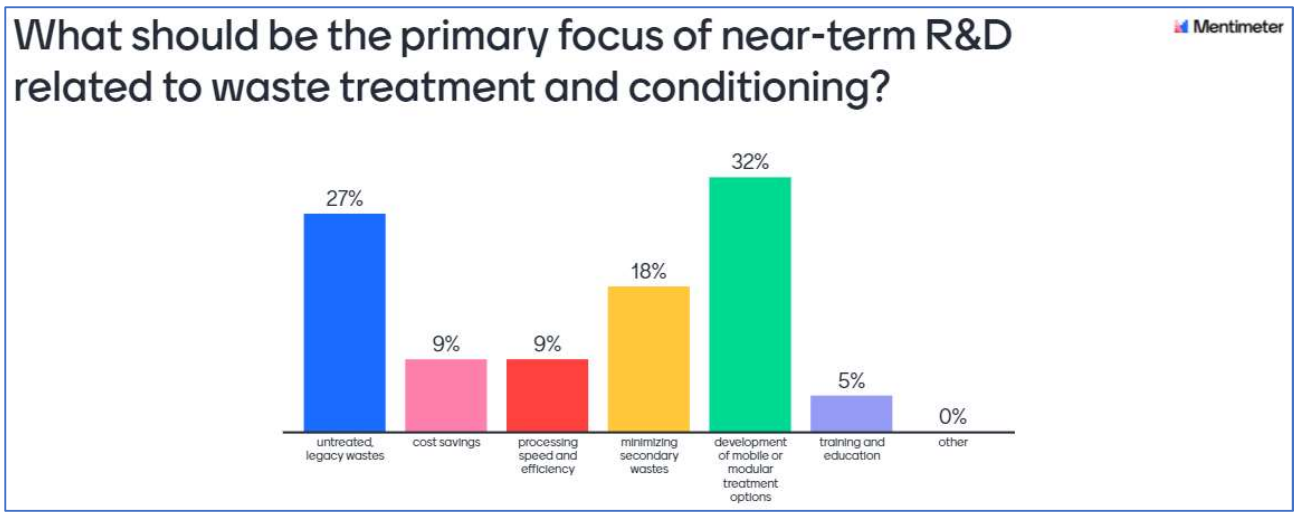

What is the biggest challenge in predisposal management of radioactive waste?
Mentimeter
27%
27%
23%
0%
5%
5%
14%
0%
segregation and sorting
classification and characterisation
treatment and conditioning
transport
monitoring and storage
financial issues
regulatory compliance
other


What should be the primary focus of near-term R&D related to waste treatment and conditioning?
Mentimeter
27%
9%
9%
18%
32%
5%
0%
untreated, legacy wastes
cost savings
processing speed and efficiency
minimizing secondary wastes
development of mobile or modular treatment options
training and education
other