PREDIS

Newsletter #8 July 2024

IN THIS ISSUE:

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For PREDIS (Predisposal Management of Radioactive Waste)

after almost four years of hard work, it is time to finalise the project, look back with pride and say thank you.

The PREDIS project has been excellent: fruitful collaboration, impressive technical achievements with dedicated laboratory experiments and modelling, tremendous human capacity building through trainings and guidance documentation, successful field demonstrations together with end users and in the end a lot of useful results and innovation. We promised to achieve demonstrating new solutions, addressing project drivers from the end users' (industry's) point-of-view, fostering deeper collaboration between experts from several EU Member States, training new experts and updating and revising predisposal guiding documents, and we definitely achieved all of these targets. Of course, there are also many lessons learnt that can improve the work in future projects.

The project results are described in the public deliverable and milestone reports that can be accessed at the PREDIS website (https://predis-h2020.eu/). The final documents are still under preparation, but after August 2024 all the public ones will available, along with the numerous newsletters, webinar presentations, domain insight trainings and other interesting documents and recordings. We hope to include most of them also for future use into the coming EURAD-2 website and when relevant among the Euratom and IAEA Wiki for wider distribution and archiving.

Highlights of the PREDIS project have definitely been the whole consortium workshops with a lot of colleagues sharing their results and having dialogue with the end users, but also discussing other issues. What has been very special during the project, has been the community that PREDIS partners have formed with sharing working and collaboration experiences. Laboratory and facility visits during the workshops at VTT (Finland), SCK CEN (Belgium) and CEA (France) were insightful as it was interesting to see the lab work behind all technical developments. During the Final Conference of PREDIS in Avignon, France, in early June 2024, there were excellent presentations on the scientific achievement and also overviews and industrial panel discussions of the impact of these developments. PREDIS project will once again publish the proceedings from the conference presentations.

Thank you to all PREDIS partners who have contributed to the common goals. Special thanks go to our wonderful Management Team as the Work Package Leaders and their deputies. And a very warm thanks to my co-coordinator Erika, who has been essential for the project since the beginning. I would also like to remember our Ukrainian partners KIPT and SI IEG NASU and the PREDIS partners, who have made it possible for them to continue their work in the project.

End users and stakeholder – we are very grateful to have you in the project with us and hopefully this collaboration will carry on within EURAD-2 to be further strengthened in future. PREDIS project has been there for you.

Wishing you a wonderful summer!
- Maria Oksa (VTT), Project Coordinator

Members of the PREDIS Management Team, Project Officer and industrial guest speakers, enjoying the gala dinner at PREDIS Final Conference in Avignon in June 2024.

PREDIS Final Conference

The PREDIS Final Conference was organised 2-7 June in Avignon, France, hosted by partner and Work package 5 (liquid organic wastes) leader CEA (France). The event was intended for all PREDIS partners, end users and interested stakeholders, and included approximately 160 people in-person and another 30 online. The Final Conference highlighted the achievements of the entire project, both from the technical as well as industrial impact views, and outlined the way forward for implementation of the results. The presentation by Hans Forsström, chair of the EC's external review of PREDIS project implementation, summarised the external recognition for project achievements, as shown in Figure 1 excerpt from the conference. The coordinators and the Management Team congratulate the project participants on their efforts towards delivering an outstanding impact towards sounder and more efficient pre-disposal of radioactive waste! A few photo highlights are shared at the end of this newsletter.

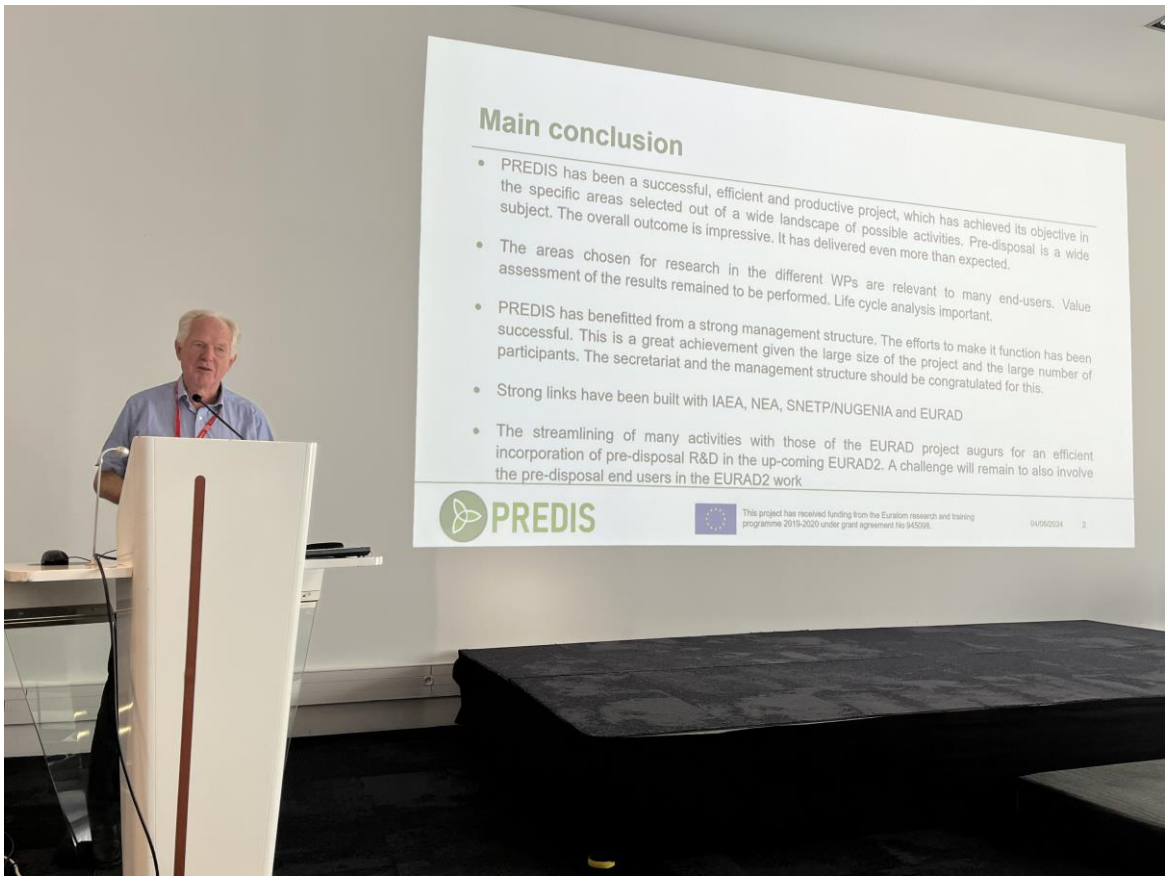


FIGURE 1. PREDIS EXTERNAL REVIEW SUMMARY, BY HANS FORSSTRÖM, CHAIR.

Looking Beyond PREDIS

Though our 4-year PREDIS project is drawing near its conclusion, we hope our motivated community will continue to be highly involved with the future activities. The new 5-year EURAD-2 joint partnership is expected to start in October 2024 based on the positive evaluation by the European Commission (Euratom program) in spring 2024. The kick-off partners meeting of EURAD-2 is anticipated to be October 23-24, 2024 in Brussels, but please stay tuned to the PREDIS web page for further information. In EURAD-2, predisposal waste management themes are covered in the new work packages (WPs) on characterization (WP5 ICARUS), condition of wastes (WP6 STREAM) and long-term safety of conditioned wastes (WP7 L'OPERA). Low- and intermediate level waste and pre-disposal issues are also linked in other WPs addressing topics like impacts of climate change (WP11 CLIMATE), digitalization (WP15 DITOCO2030) and SMR waste issues (WP4 FORSAFF) among others. Thanks to all of the PREDIS partners who were very active in preparing the proposal and also taking leadership roles as we move forward with good momentum from PREDIS to now join with EURAD (2019-2024). EURAD-2 anticipates having a second wave of funding of additional WPs to be planned in 2025 and work starting in 2026, with topics decided by the 3 EURAD Colleges. So please stay in contact with the College chairpersons for more information. Details about the EURAD-2 planning process, final WPs and College chair contact info can be found on the PREDIS web page https://predis-h2020.eu/publications-and-reports/ in the section "Towards EURAD-2".

Results of the PREDIS project will be highlighted at the FISA-EURADWASTE 2025 conference (held jointly with SNETP Forum 205) in Warsaw, tentatively planned for 12-16 May 2025. This event has over 500 attendees and presentations are expected to highly achievements from the past 3 years of Euratom projects. Please stay tuned to the PREDIS web page for further details and solicitation of jointly holistic presentations. Information about the previous 2022 event can be found at https://www.sfen.org/evenement/fisa-2022-euradwaste-22/.

FIGURE 2. PREDIS MANAGEMENT TEAM AT THE PREDIS FINAL CONFERENCE 2024.

Work Package Updates

WP2: Strategic Implementation

Setting the future direction for Predisposal R&D

Great progress has been made since the last newsletter with all the remaining strategic tasks either completed or expected to complete on schedule. In April the team led by Alan Wareing (NNL) finalised the PREDIS Strategic Research Agenda (SRA). This final issue includes a summary of the technical work undertaken within each of the PREDIS work packages over the course of the project. An introduction to the ongoing Future Horizon Scanning activity has also been included.

Horizon scanning is a well-established methodology that enables organisations to anticipate and prepare for future changes by systematically identifying emerging trends and potential disruptors/ disruptions; considering how changes in the future 'nuclear landscape' could affect the predisposal research needs and opportunities.

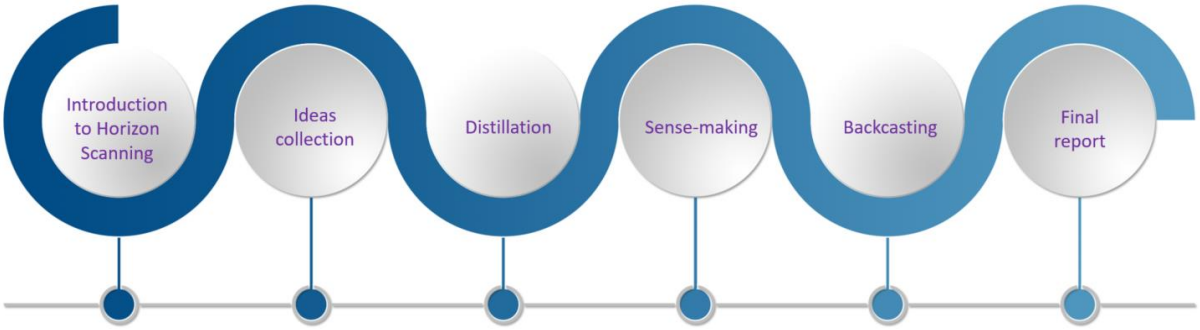


FIGURE 3. TYPICAL PHASES IN THE HORIZON SCANNING PROCESS.

The approach involves gathering and analysing information from a wide range of sources, including scientific literature, industry reports, and expert opinions, to identify potential technological developments, opportunities, and challenges. The information was gathered through an open survey on the PREDIS platform collecting more than 100 original ideas from 9 countries.

The aim of the horizon scanning exercise is to provide insights and recommendations for policymakers, regulators, industry leaders, and researchers, to help them navigate the rapidly evolving nuclear landscape and shape the future of the nuclear industry. This Horizon Scanning work and its outcomes will be reported separately in addition to the SRA.

The End User and Stakeholder Groups interactions have remained strong, indeed NAAREA from France have joined as a new end user. The PREDIS team would like to thank all end users, stakeholders and interested parties that have participated in our workshops, webinars, surveys and focus groups, your input has been valuable in helping to shape our work and outcomes.

Waste Acceptance Systems

With respect to the Waste Acceptance Criteria and Systems (led by Lumir Nachmilner, CVRez), the team have finalised and issued the public Deliverables 2.6 Guidance on waste form qualification and 2.7 Guidance on establishing generic waste acceptance criteria. This completes the suite of guidance reports, which are now available. Additionally, the team have also developed two blogs. The first on 'Waste form qualification' by SURO (2024) and the second 'Separation and determination of actinides and Zirconium-93 from radioactive waste and mineral samples' by ISOTOPTECH (2024).

Life Cycle Analysis

As we are now into the final months of the project there is an increasing focus on the completion of the Life Cycle Analysis (LCA) and Life Cycle Costing (LCC) tasks. Indeed, Dr Laurence Stamford (University of Manchester) presented an update at the Final PREDIS Conference. This work is progressing well with our two PhD researchers Rachael and Joel working on preparation of papers for publication.

FIGURE 4. DR LAURENCE STAMFORD PRESENTING AT THE PREDIS AVIGNON MEETING.

The LCA work has generated a lot of interest in the PREDIS consortium and in the broader community and we were please to present a two-day training course in May, hosted by Laurence, Joel and Rachael. The outcomes of the training can also be accessed via the PREDIS web page for future use.

WP3: Knowledge Management

Student group meeting

The last PREDIS students meeting on 3 June 2024 was hosted by Maria Abada (Amphos 21). The targeted audience was students and young professionals in the pre-disposal waste management sector. The main aim of the students get-together was to hear the students summarising their work within PREDIS and describing their experience being part of the PREDIS project. There was also time for students to give feedback on the knowledge management activities in WP3, as well as how the communication channels between the project and students worked out. It has been a pleasure to work with the PREDIS students and to interact with them and let them take own initiative to partly steer the training and mobility programme so that it fitted their interest best. The KM work package leaders would like to express a special thanks to the student group representative Jessica McWilliams (University of Sheffield) for guiding the student group for 3 years. The student's professionalism and joyfulness has enriched the PREDIS community.

FIGURE 5. YOUNG GENERATION PARTICIPANTS TO THE PREDIS FINAL CONFERENCE, AND THE LEADERSHIP OF JESS MCWILLIAMS.

This work package is led by Paul Carbol (JRC), but Alba Valls (Amphos 21), co-leader of the KM WP with Jiri Faltejsek (UJV), presented the knowledge management work and achievements made during the complete duration of the PREDIS project. It could be summarised that all key performance indicators set at the beginning of the project were reached and that many "extra" initiatives were successfully added, to the benefit of the pre-disposal community. Such initiatives were for example 19 webinars, a PREDIS glossary, contributing to form a student group with 40 students and disseminating the PREDIS KM activities beyond the PREDIS community through presentations at 11 conferences and publishing in 7 proceedings. The demanding work to keep the mobility programme (in total 53 mobilities) to run smoothly for all years was previously managed by Vaclava Havlova and presently by Jiri Faltejsek. Furthermore, the team has worked intensively to integrate all important actors, given in the figure below, into the PREDIS KM programme.

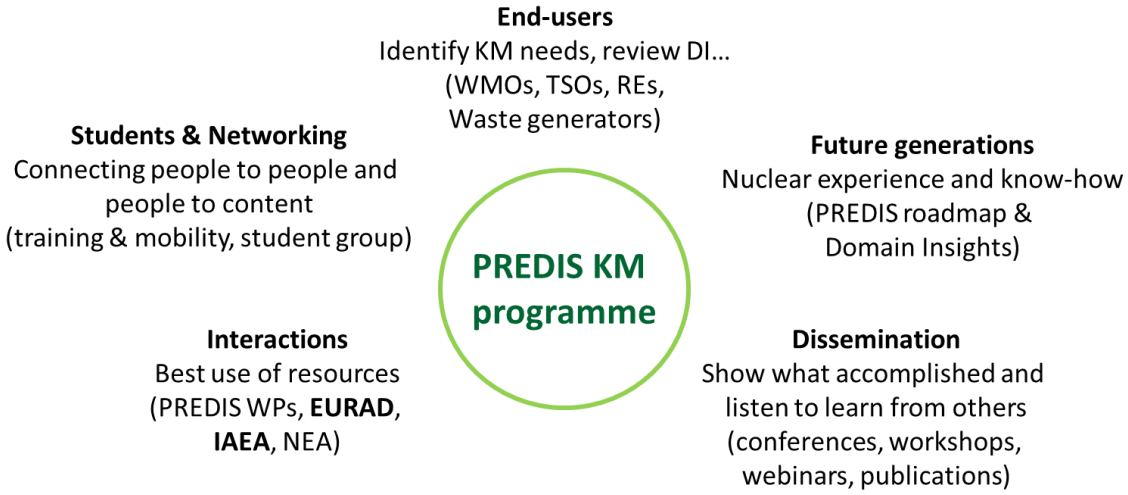


FIGURE 6. PREDIS KM PROGRAMME.

Special thanks to all actors contributing to achieve all KM goals. These actors were WP leaders, partners contributing with internships and trainings, as well as individuals from organisations within the pre-disposal community that enjoyed and participated to the organised activities and provide their feedback to keep improving our KM programme.

Young Generation group, at the final conference Gala Dinner, Avignon, June 2024.

WP4: Innovations in metallic treatment and conditioning

WP4 activities have reached major achievements including optimization of processes as well as innovation. With regards to the task on optimization of processes for decontamination and effluents treatments, a new optimized chemical treatment process called COREMIX has been proposed based on the conventional CORD process. Indeed, the optimization was achieved by replacement of toxic and unstable chemicals with products with lower environmental impact but also by reducing the treatment time (less energy consumption and less CO_2 released). In addition, the effluent treatment was optimized via proposing a simple and efficient precipitation process well compatible with WAC for the conditioning step. In terms on innovation, a magnetic gel was developed and being tested for decontamination of metallic waste with complex geometry (Figure 7). With respect to the task on characterization of metallic waste, many parameters, that may affect the NDC gamma spectrometry measurement results, have been tested and include the geometry of segment, activity inhomogeneity, measurement efficiency, pipe direction, etc. (Figure 8). The optimized method allows determination of activities of Cs-137 and Co-60 at the level of clearance in 1-2 min (amount of metallic waste about 100 kg). Optimization of scaling factor has been made as well allowing better characterization of metallic waste. Furthermore, several radiochemical procedures for DTM measurements were developed and an inter-comparison exercise will be held during 2024. For the task dedicated to encapsulation of reactive metallic waste in magnesium phosphate cement (MPC) significant optimization was made with respect to formulation by introduction of low-cost raw material (e.g., reactive MgO) and by recycling of materials (e.g. slag furnace). The resulting MPC materials exhibited very good mechanical and chemical properties while preserving from fast corrosion of reactive metallic waste (Al, AlMg, steel) (Figure 9).

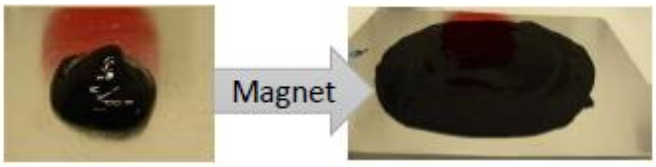


FIGURE 7. MAGNETIC GEL PREPARED BY CEA FOR DECONTAMINATION OF METALLIC WASTE WITH COMPLEX GEOMETRY.

FIGURE 8. METALLIC PIPES WITH DIFFERENT DIMENSIONS TESTED FOR THE OPTIMISATION OF THE NDC GAMMA SPECTROMETRY TECHNIQUE.

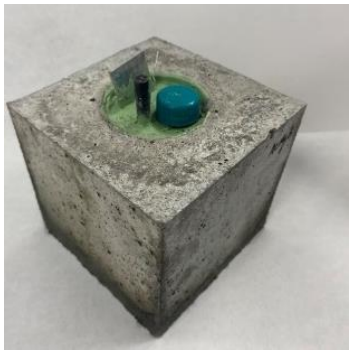


FIGURE 9. AL CORROSION IN CONTACT WITH MPC CEMENT SURROUNDED BY ORDINARY PORTLAND CEMENT (OPC).

WP5: Innovations in radioactive liquid organic waste (RLOW) treatment and conditioning

We have reached the final year of the project and with just a few months to go before the end of this incredible journey, we would like to thank our task leaders, students and member partners for the incredible collaboration, commitment and contribution throughout Work Package 5 (WP5).

Earlier this year, in March, WP5 presented an overall status report to the European Commission panel reviewers, focusing on the objectives, impacts and outcomes of the research and development activities. The feedback from the four external reviewers was overwhelmingly positive!

Another important event in 2024 was the PREDIS Final Conference, which took place in Avignon, France. This was a great opportunity to present the results of WP5 to other WP partners, EUG and stakeholders, but also to reflect and collect feedback from all WP5 partners on lessons learned, first-hand experience of good practices implemented in PREDIS and possible improvements for future projects. Feedback from participants conveyed that the collaboration between partners was key to the project and that the training opportunities were very useful for their professional development.

FIGURE 10. WP5 WORKSHOP MEETING AT THE PREDIS FINAL CONFERENCE 2024

As our four-year PREDIS project is coming to an end. In this final newsletter, we would like to give an overview of the impacts achieved by Work Package 5. The main objective of WP5 was to investigate and develop innovative direct conditioning solutions by implementing geopolymers and related alkali-activated materials as mineral binders, with experimental R&D main activities, carried out at laboratory scale in inactive conditions, but also validation tests with real waste and feasibility scale-up tests. The tasks defined in WP5 enabled the following impacts to be achieved:

A shared view of pre-disposal solutions for RLOW:

All partners have worked together to increase the knowledge and understanding on predisposal solutions for RLOW across different countries, which could be transferred into management strategies applied at national or European level. In Task 5.2, the RLOW inventory questionnaires of the PREDIS partners and the EUG member were fundamental for the identification of the reference wastes and the selection of the raw materials and additives for the formulation of the matrices.

Availability of a treatment and conditioning process for RLOW up to TRL 6:

During Task 5.3, the partners first investigated basic formulations and processes for direct conditioning of radioactive liquid organic waste (RLOW) in geopolymer and related alkali-activated materials, all promising conditioning formulations were further investigated and grouped into three families of formulations based on: metakaolin (MK), blast-furnace slag (BFS), and a mixture of fly ash, BFS and MK. The optimisation and robustness of these formulations were studied with surrogate RLOW, and the optimised reference formulations were further investigated with real RLOW. Feasibility scale-up tests were carried out at different drum size up to 100L (20-30% vol. pilot-scale) for the MK based formulations, leading to a technology readiness level (TRL) of 6. The TRL of the other developed formulations has increased during these years, TRL 5 for the BFS-based and TRL 4 for the Mix-based, but further efforts and more R&D are required to achieve a technology readiness level of 6.

Disposability assessment related to Waste Acceptance criteria (WAC)

For the geopolymer matrices developed, Task 5.4 investigated the ability to immobilise waste over long periods of time, focusing primarily on analysing the durability of matrices containing waste and their ability to withstand both radiation from the waste and accidental or seasonal thermal stress. Leaching and carbonation test allows to investigate the capacity of the geopolymer matrices to physically immobilise RLOW and to ensure that chemical exchange with the surrounding environment are not deleterious (regarding the investigated period). Initial results on the thermal behaviour of the tested formulations (MK-based and MIX-based) showed microcracking of the matrices under thermal cycling. The results obtained also showed the need to carry out compatibility studies of the waste with respect to the fresh rheology of the matrices to obtain compatible viscosities and avoid bleeding or strong heterogeneity of the complex (RLOW and GP matrices). Further investigation of the behaviour of the geopolymer matrices at high temperatures and under fire-like conditions are still required, as the obtained results highlighted the important role of the thermal and hydric gradients in reducing the strength capacity of these matrices.

As part of Sub-task T5.4.9, a disposability assessment has been carried out (Deliverable D5.4). The Disposability assessment report provides technology developers and end-users with an objective assessment of the likely performance of waste packages produced via the direct conditioning route. The following outputs are included:

- Discussion and identification of the key disposability considerations of geopolymer wasteforms developed in PREDIS WP5.
- Linking the disposability considerations to wasteform and waste package characteristics, drawing on experimental results from Task 5.4 to assess and discuss the suitability of these wasteforms for final disposal in geological or near-surface disposal facilities.
- Providing, through a colour-coded Red Amber Green (RAG) system, an indication of disposability aspects that are seen as non-challenging (green), slightly challenging (amber), or extremely challenging (red).

This study is the first step in evaluating the disposability of three geopolymer wasteforms involving a Metakaolin (MK)-based geopolymer, a Blast Furnace Slag (BFS)-based geopolymer and a geopolymer based on a mixture of different raw materials, including MK, BFS and Fly Ash (FA), referred to as the MIX formulation.

To evaluate the disposability considerations applicable to the range of proposed or operating LLW and ILW disposal facilities across Europe, a set of five generic disposal facilities were defined at depths spanning from surface to deep geological disposal. These generic facilities are not necessarily consistent with any one facility, but instead defined to capture the broad characteristics of a single ‘class’ of facilities.

Disposability assessment is country-dependent as the criteria and their limits are different from one country to another. The experiments were mainly realised at a laboratory scale, meaning that some criteria cannot be assessed, and they will be mainly package- and radioactive inventory-dependant. Bearing these limitations in mind, a sub-set of criteria were assessed, including physical form, mechanical stability, homogeneity, void

space, presence of free liquids, chelating/complexing agents, and leaching. The results show that geopolymers have a promising future as encapsulation matrices.

Preliminary technical, economic and environmental analysis of the direct conditioning route developed in PREDIS WP5 (Value Assessment)

Task 5.5 was dedicated to the preliminary technical, economic and environmental analysis of the direct conditioning route developed in PREDIS WP5. This analysis, termed value assessment (Deliverable D5.5), brought together research results in terms of waste loading, conditioning matrix performance, process cost, and product disposability to capture the overall performance of the direct conditioning route. These results were compared with current waste management practices to provide a comparison of how the novel direct conditioning route performs against current practices over a range of criteria.

Direct conditioning of contaminated oils and scintillation cocktails using Metakaolin-based, Blast Furnace Slag, or the MIX-based geopolymer formulations was found to result in better operational safety outcomes, compared with the current two-step cementation approach. The environmental impact of the overall process is also lower, whilst significantly reducing conditioning, storage and disposal costs. Several challenges were identified in the form of raw material procurement and purity. The need for further research and development to achieve a TRL of nine was also acknowledged, and is reflected in the EURAD-2 proposals.

Direct conditioning of solvents using MK-based geopolymers was compared against a baseline comprising incineration followed by cementation. Geopolymer conditioning was found to result in improved safety and environmental outcomes. Current findings indicate, however, that disposal is likely to be more costly due to the relatively lower geopolymer waste loading compared with those the loading achieved when thermal treatment is used.

Overall, direct conditioning of RLOW using the geopolymer formulations developed in PREDIS WP5 was found to result in positive economic, safety, and environmental outcomes.

A fully cooperative working program

Work Package 5 has been a real team effort! We have seen an amazing level of teamwork across all partners working on WP5, and we have also worked with other work packages, stakeholders and end users to achieve our objectives. Information and data sharing has been key to implementing geopolymers and related alkali-activated materials as mineral binders, and development of a direct conditioning route for RLOW as a common pre-disposal solution.

Although PREDIS has come to an end, the outcomes of this work package, deliverables, milestones, presentations and publications will remain accessible on the PREDIS webpage (here). In the coming months, we will be finalising the public deliverables, which include D5.6 “Dissemination report use of geopolymer matrices for the immobilisation of liquid and solid radioactive wastes” and D5.7 “Final report on WP5 interactions with stakeholders/end users”. Stay connected with us through our website.

WP6: Innovations in radioactive solid organic waste (RSOW) treatment and conditioning

The focusses are now on finalising the experimental work, gathering data and providing all the information needed for the delivery of the deliverables and milestones, and the preparation of the final Workshop.

In February, a value assessment workshop was organized by GSL (UK) at which several options for the immobilization of ashes were assessed, generated by the treatment of ion exchange resins (IRIS process – CEA). These thermally treated materials were subjected to compaction (CEA, France), immobilization in a geopolymer matrix (Polimi, Italy) or by HIPping (USFD, UK). In comparison with geological disposal facilities, the capacity of thermally treated waste streams to 'type' near-surface or intermediate-depth disposal facilities was assessed.

Most of the leaching experiments to evaluate the durability and the stability of the reconditioned matrices have been carried out under experimental conditions according to the agreed protocol defined in PREDIS. For some WP6 partners, similar experiments were performed under more specific conditions directly linked to national requirements or to the nature of the immobilization matrix (e.g., geopolymer in contact with ammonium nitrate solution). Due to the diversity of the investigated samples, it was also necessary to harmonize the results for a direct comparison depending on the conditioning option. Therefore, and based on international standard, a calculation file was created and shared with the WP6 community in order to determine the Normalized Loss (NL), Cumulative Fraction Leached (CFL) or Leaching Indices (LI) for further performance assessment exercises. This calculation file was made available to the PREDIS consortium but also to the scientific community outside the project, on request. Other typical parameters were measured for cement-based and geopolymer materials samples such as the compressive strength. By studying post-mortem samples, more fundamental research has also carried out to determine particular mechanisms governing the behaviour of the reconditioned materials under specific conditions, and to provide important parameters for building models, including on a drum scale model. Finally, and on the basis of the available (inter-)national WACs, it will be possible to make a selection of the most promising matrices for further investigations in the framework of national research programs or European projects (EURAD-2).

FIGURE 11. PREDIS WP6 FINAL TECHNICAL WORKSHOP WITH PROJECT PARTNERS.

FIGURE 12. WP6 WORKSHOP MEETING AT PREDIS FINAL CONFERENCE 2024.

WP7: Innovations in cemented waste monitoring

PREDIS WP7: Successful final meeting

The final project meeting was a success for work package WP7, highlighting significant achievements to a broader audience. Before this, an internal work package group meeting was held to discuss the latest results.

The project successfully installed external and internal sensors in nuclear waste containers, crucial for monitoring their safety and integrity. A state-of-the-art digital twin technology was developed to model processes occurring within the containers, allowing real-time simulation and analysis for enhanced predictive maintenance and risk assessment. Additionally, a comprehensive database was created to manage all relevant experimental data, improving transparency and efficiency. An advanced decision framework was also implemented to assist end-users in effectively handling and managing nuclear waste containers.

To demonstrate the effectiveness of these achievements, a case study was conducted, involving tests and real-world scenarios with nuclear waste containers. The results confirmed the reliability and robustness of the new systems, highlighting improved monitoring capabilities, predictive analytics, and enhanced decision-making support.

The final meeting included presentations from task leaders, with detailed explanations of the technologies, and an engaging Q&A session with the audience. Positive feedback and interest from the wider public underscored the project's success and its potential impact on the safe and efficient management of nuclear waste.

A closer view is given on Task 7.4 in this newsletter.

An exploratory digital twin case study for Alkali Silica Reaction (ASR) pathology in cemented waste drums

One particular objective of Task 7.4 was to develop a real-life prototype of a digital twin (DT) reflecting a waste package. For this, an alkali silica reaction (ASR) pathology in cemented waste drums was chosen as an exploratory case study. Belgium partners SCKCEN andMagics Technologies (Magics) along with Belgoprocess (BP) as an end-user, collaborated on this multi-disciplinary endeavour combining experimental and numerical analysis with real-time data acquisition. At SCK-CEN's laboratory, hydration behaviour, elastic and strength properties, ASR expansion and

autogenous shrinkage properties were determined on small samples to obtain a digital twin model that reflects the behaviour of ASR at the drum-scale. To validate the model, four 220L drums were filled with various cement recipes to simulate ASR process under both natural and accelerated conditions where the recycled concrete aggregates (RCA) and stainless-steel drums were supplied by BP.

For both the lab- and drum-scale experiments, a variety of sensors were designed and deployed by Magics, and interfaced through different data acquisition systems to a local server that, depending on the experiment, communicated the data to the cloud for the purpose of data storage, data analysis, dashboard and automated alerting. VTT (Finland), a Task 7.5 partner, provided the necessary interface from the Magics server to the PREDIS WP7 dashboard to relay live data on temperature and strain measurements. For the digital part, a simplified coupled thermo-hydro-mechanical model for ASR process was implemented by SCK CEN with contributions from the Task 7.4 partners BAM (Germany), PSI (Switzerland), NRG (Netherlands) and AMPHOS21 (Spain).

Laboratory scale experiments clearly demonstrated that a specific cement formulation based on RCA has the highest potential for forming ASR. However, even after a year, the drum scale experiments for all recipes still predominantly show autogenous shrinkage. This implies extremely slow ASR kinetics in reality. The model is capable of simulating reasonable qualitative/quantitative trends for temperature and strains. The drum scale experiments are planned to continue beyond the life of PREDIS project. In particular, within the forthcoming EURAD-II project (ICARUS WP), it is proposed to disassemble these waste drums after a reaction time of two-three years and to analyse their material properties with innovative characterizations, including spectroscopic methods to determine the nature and extent of ASR and alteration in microstructure and mineralogy. These post-analysed properties will be used to correlate with the sensor signals.

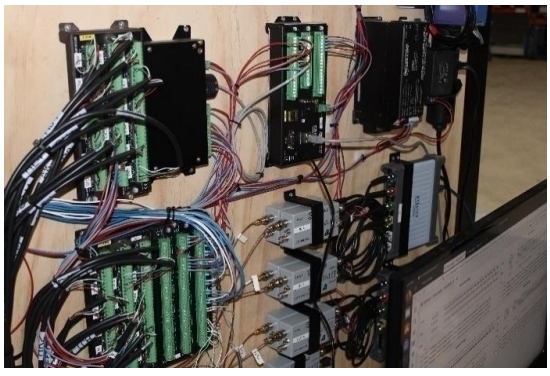


FIGURE 13. CONSTRUCTION OF CEMENTED WASTE DRUMS AT THE EURIDICE ABOVE GROUND FACILITY IN MOL, BELGIUM.

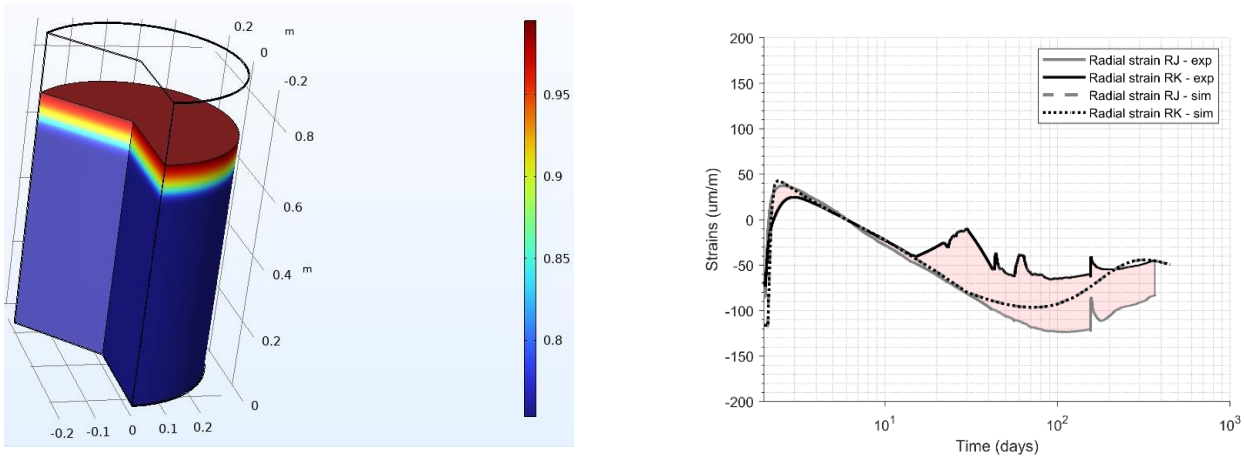
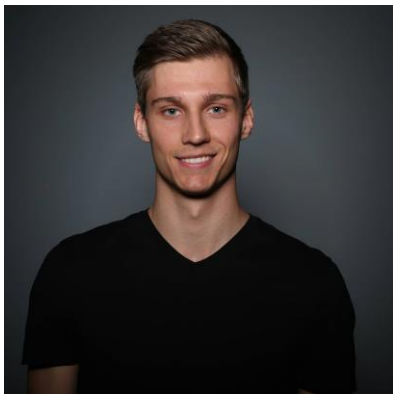


FIGURE 14. SIMULATED MOISTURE DISTRIBUTION IN TERMS OF DEGREE OF SATURATION (LEFT), AND COMPARISON OF RADIAL STRAIN EVOLUTION IN A DRUM THAT SHOWS NO ASR EXPANSION YET (RIGHT).

FIGURE 15. WP7 WORKSHOP MEETING AT PREDIS FINAL CONFERENCE 2024.

Student profiles



Mathurin ROBIN is a nuclear engineer specialising in the decontamination of radioactive effluents with a Master's degree in analytical chemistry from Rennes 1. During the last year of his Master's degree, he worked at the IRSN on the optimisation of a protocol for the analysis of radioactive isotopes in environmental samples. This experience opened the door to a PhD at the Subatech laboratory in Nantes, France. His thesis is part of WP4 of the PREDIS project, where he is conducting research on the "development of a radioactive effluent decontamination process and its application to chemically decontaminated metal alloys".

Through PREDIS and its mobility programme, he had the opportunity to attend courses on LLW/ILW management at UJV Řez in the Czech Republic. He was also able to attend a training course on radioactive waste management operations at Orano's La Hague site, which gave him the opportunity to interact directly with stakeholders in nuclear waste management in France. These various courses have allowed him to develop his knowledge and to present his research as a poster in front of recognized experts during the IGD-TP conference in Zurich.

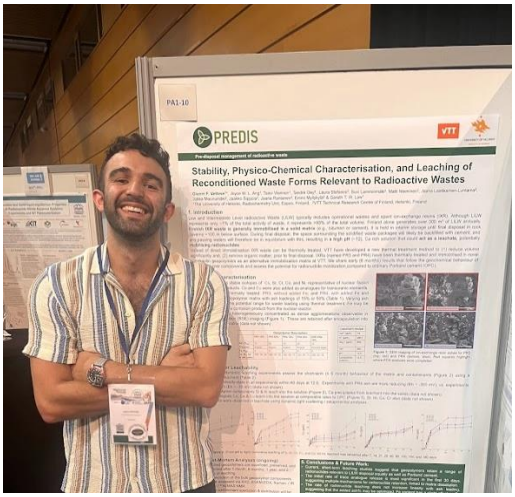
Mathurin also had the opportunity to present his latest results to international experts at the DEM 2024 conference and to PREDIS end-users at the PREDIS final conference, both in Avignon. Part of his work is currently being published and he plans to defend his PhD at the end of 2024.

Sara KOUBEISSY is a civil engineer with a master's degree in Sustainability Engineering from INSA Toulouse University, France. Her master's internship in geopolymers allowed her to initiate her research work on alkali-activated materials (AAM), specifically focusing on geopolymers.

Since September 2021, she has been pursuing a PhD on "Durability of geopolymer matrices subjected to carbonation and leaching" at Centrale Lille Institute, France. Her PhD work is supported by the PREDIS project under WP5. Her PhD work focuses on studying the leachability of the geopolymer formulations under different alkaline and acid solutions. Moreover, she studies the effect of natural and accelerated carbonation on the performance of formulation matrices.

During the previous years, Sara participated in the NUWCEM conference in Avignon, France and the RUGC conference held in Lille, France which was a great opportunity as it allowed her to present her work and create connections. She attended the PREDIS annual Meetings 2022 and 2023 where she summarized her work within the WP5 for the end-user group in Helsinki, Finland and Rome, Italy respectively. She has also taken part in the PREDIS course on LLW/ILW management in conjunction with the student gathering at UJV Řez, Czech Republic.

Sara will attend the PREDIS final meeting next June. She is very excited to present her results there and to be chosen to present the student in the public technical workshop.



Gianni Francesco VETTESE is an early career researcher at the University of Helsinki, Finland. Gianni is an environmental radiochemist with a broad range of interest subjects, including radioactive waste disposal (very low-, intermediate-, and high-level radioactive wastes), radioactive contaminated land, naturally occurring radioactive materials, and hot-particle characterisation and behaviour. Gianni joined the PREDIS project as a post-doc in 2020 and he works in WP6 focusing on the leaching behaviour and evolution of geopolymers which have been used as a matrix for the immobilization of spent ion-exchange resins.

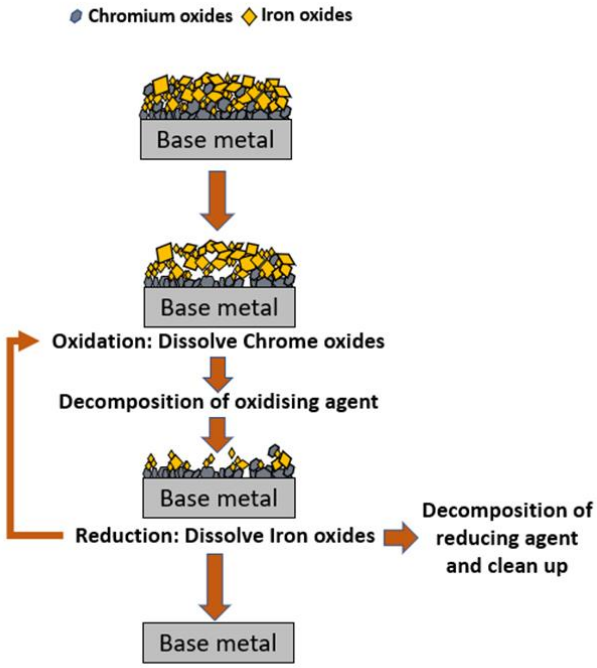
The PREDIS mobility programme has afforded him the ability to attend two conferences: the 19th Radiochemical Conference (2019), and the 18th International Conference on the Chemistry and Migration Behaviour of Actinides and Fission Products in the Geosphere (2023), in Mariánské Lázně (Czech) and Nantes (France) respectively). And it also helped him attend the PREDIS annual workshop (Mechelin, Belgium, 2023). In each of these events, Gianni has shared his work where he received valuable feedback and insights from peers, built a strong international and multidisciplinary network, and made new friends. This June, the mobility programme will also provide the opportunity for Gianni and his PhD student, Taavi Vierinen (who also worked on the PREDIS project as part of his master's project) to attend and the PREDIS final conference (Avignon, France, 2024).

PhD theses abstracts

Example Abstracts of doctoral theses produced within PREDIS

Aditya RIVONKAR Optimization of chemical decontamination methods for radioactive metals
Organisations: IMT Atlantique/SUBATECH (France)

In the scope of the PREDIS project, my thesis explored the optimization of chemical decontamination methods tailored for radioactive metals. Specifically, focused on refining the Chemical Oxidation Reduction with nitric permanganate and oxalic acid MIXture (COREMIX) process, a variant of the widely used CORD process.



The study encompassed experimentation on distinct sets of samples representing materials found in nuclear power plants and fuel reprocessing plants. Notably, optimization efforts resulted in significant achievements, including a 50% reduction in contact times, cycle numbers, and effluent volumes for stainless steels from nuclear power plants. Importantly, these enhancements were achieved without the need for complex UV applications, simplifying the process and reducing energy consumption, complexity, costs, waste volumes, and environmental impact. Moreover, when applied to more resilient materials like Ni alloys, the optimized COREMIX process exhibited reductions in cycle times and identified key limiting factors.

Extending the optimized COREMIX process to materials used in reprocessing applications showed significant efficiency gains, with a single cycle demonstrating promising efficacy and potential for further optimization. The optimization efforts also led to increased corrosion rates, surpassing well over 100% in some cases, indicating suitability for decommissioning applications.

Additionally, the entire process adhered to waste acceptance criteria (WAC) standards, with effluent pretreatment through thermal destruction of oxalic acid (COREMIX-H) ensuring compliance. Life Cycle Assessment (LCA) studies highlighted the process's low environmental impact at the laboratory scale, with electricity generation identified as the primary contributor to environmental footprint.

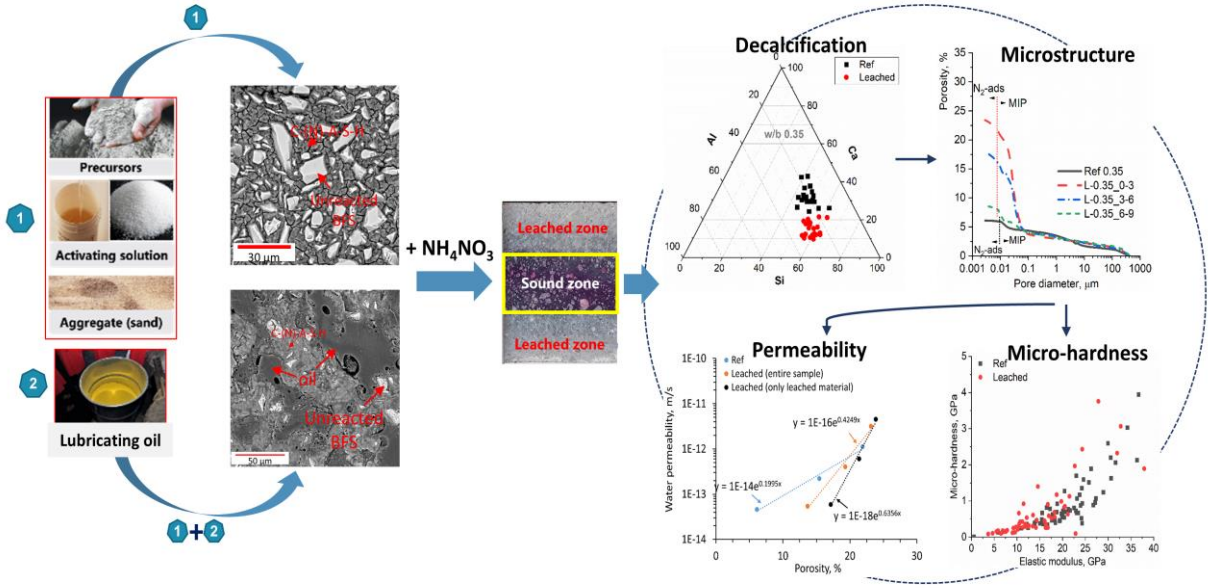
In conclusion, the optimized COREMIX process represents a significant advancement in chemical decontamination methods for radioactive metals, offering enhanced efficiency, reduced environmental impact, and improved waste management practices.

Thi NHAN Physico-chemical evolution of geopolymers in contact with aggressive environments
Organisations: KU Leuven/SCK CEN (Belgium)

The study investigated the performance of alkali-activated materials (AAMs) in aggressive environments, focusing on formulating AAMs suitable for nuclear liquid waste immobilization. Carbonation and leaching, key degradation processes, were analysed on AAM mortars with high-calcium content (alkali activated GGBFS - AAS) and calcium-free metakaolin-based geopolymers. Various characterization techniques, including XRD, FTIR, TGA/DSC, MAS NMR, ICP-OES, SEM/EDS, nitrogen adsorption, MIP, and micro-indentation, were employed. Water permeability and dissolved gas diffusivity studies were conducted, along with the development of thermodynamic models for carbonation and leaching. This study also assessed the immobilization capacity of AASs and metakaolin-based geopolymers with different liquid wastes, including tributyl phosphate (TBP) and lubricating/motor oils (e.g., Nevastane and Shellspirax).

Results revealed significant structural changes in AAS due to carbonation and leaching (e.g., decalcification and dealumination of C-A-S-H), while metakaolin-based geopolymers were less affected. The evolution in microstructure and transport properties of both types of AAMs under carbonation and leaching was remarkably influenced by water-to-binder ratios. Leaching coarsened AAS microstructure but reduced total porosity in metakaolin-based geopolymers due to $Al(OH)_3$ formation. Accordingly, water permeability of AAS increased, while permeability and diffusivity of metakaolin-based geopolymers slightly decreased after 28 days of leaching. Both materials showed an exponential relationship between total porosity and water permeability, as well as between total porosity and diffusivity of metakaolin-based geopolymers, before and after leaching.

Moreover, both AAS and metakaolin-based geopolymers exhibited promising immobilization capacity for various wastes when surfactants were employed. Metakaolin-based geopolymers showed better compatibility with liquid wastes compared to AASs. AAS demonstrated effectiveness primarily with high-viscosity liquids like lubricating oils, with waste loading reaching up to 40 vol.%, showing promising durability of the waste-forms.



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Newsletter #8 July 2024

Partner Spotlight

In this 8th Newsletter, we will highlight the rest of our partners (not covered in earlier newsletters) from Germany, France, Czech Republic and Switzerland

Forschungszentrum Jülich (JULICH) makes vital contributions to solving major challenges facing society in the fields of information, energy, and bioeconomy. It focuses on the future of information technologies and information processing, complex processes in the human brain, the transformation of the energy system, and a sustainable bioeconomy. JULICH develops simulation and data sciences as a key research method and makes use of large, often unique, scientific infrastructures. With more than 7,200 employees, JULICH – a member of the Helmholtz Association – is one of Europe's largest research centres. It is involved in numerous international cooperations funded through programmes like Horizon 2020 and is an active member of IGD-TP.

The Institute of Energy and Climate Research – Nuclear Waste Management (iEK-6) at JULICH performs cutting-edge research in the fields of nuclear waste management and safety, considering the process of "Energiewende", the transition of the German energy system. It performs fundamental as well as applied research and development for the safe management of nuclear wastes, covering issues from the atomic scale to the macroscopic scale of actual waste forms, waste packages or the engineered barrier system of geological disposal facilities. One part of the research agenda focuses on the development of waste management strategies for "problematic" nuclear wastes. This covers development and implementation of characterization methods, treatment, and conditioning techniques for waste streams without industrially implemented management solutions, like nuclear graphite, spent ion-exchange resins, or irradiated and contaminated chemotoxic metals (e.g., mercury). Within PREDIS, IEK-6 is contributing to WP4 with studies dedicated to the investigation of the encapsulation of beryllium in various cementitious matrices based on Ordinary Portland cement (OPC) or magnesium phosphate cement (MPC).

Directorate General-Joint Research Centre (JRC) is the European Commission's science and knowledge service. Its mission is to support EU policies with independent evidence throughout the whole policy cycle. The Directorate involved in this project is Directorate G – Nuclear Safety and Security within which the JRC's nuclear work programme, funded by the EURATOM Research and Training Programme, is carried out Within PREDIS, JRC coordinates the Knowledge Management (WP3) activities. JRC is the leader of WP3 Knowledge Management and also involved thus in WP1 project management.

Institut Mines Télécom Nantes Atlantique (IMTA) is a technological university in France. IMTA's Radiochemistry group is one of the largest research groups in its category in France. The diversity of interdisciplinary projects, which is related to major societal issues (the back end of the nuclear power cycle, health and the environment) and to the economic players in the nuclear sector (ANDRA, EDF, AREVA, etc.) allows the group to operate mainly with own resources and a large number of staff in fixed-term contracts (post-docs and PhDs). IMTA is the leader of WP4 on metallic waste streams and is also involved in WP5 activities related to radiochemistry, material science and nuclear materials, in addition to being in the WP1 project management.

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French Alternative Energies and Atomic Energy Commission (CEA) is a French state-owned organisation and a key player in research, development and innovation. Within CEA, the Nuclear Energy Division supports the French nuclear industry (EDF, Framatome and Orano as main partners) and prepares the future nuclear industry. It also carries out construction and renovation of its facilities and manages the decommissioning of its own historical facilities after shutdown, including associated legacy waste management. Within PREDIS, CEA coordinates WP5 on liquid organic wastes and contributes to WP1, WP2, WP4 and WP6.

Research Centre Rez (CVRez) is a research organisation in Czech Republic whose main aim is research, development and innovations in the field of power generation (especially nuclear). Research and development in CVRez are focused on the area of nuclear energy, nuclear reactor physics, chemistry and materials. The results are used in services for both Czech and foreign organizations and we cooperate with many research institutes and universities. In PREDIS, CVRez participates in WP2, WP5 and WP6.

Ecole Centrale de Lille (ECL) is a Higher Education and Research Public Institution, training engineers, MSc and PhD. ECL is located on the campus of Université de Lille, in Villeneuve d'Ascq, North of France. ECL is one of the supervising institutions of the research laboratory UCCS (UMR CNRS 8181), where the main persons involved in the project are also working as part of WP5 on liquid organic waste streams.

Institute for Radiation Protection and Nuclear Safety (IRSN) is the nation's public service expert in nuclear and radiation risks, and its activities cover all the related scientific and technical issues. IRSN has developed for 10 years several experiments and modelling dedicated to study porous materials (especially cementitious materials) in contact with liquid and solid aggressive environments. In PREDIS, IRSN is working on radioactive organic liquid waste treatment and conditioning using geopolymers (WP5), and co-develops new experiments dedicated to identifying the degradation of geopolymers.

Orano is a French company responsible for conditioning more than 70% of LLW, 30% of ILW for an overall volume of 10000 m^3 of waste. Up to 80% of the waste intended for the French Ground Disposal Facility is conditioned by Orano. As Orano's range of nuclear activities covers the entire fuel cycle (mining, conversion, enrichment, recycling, dismantling and decommissioning), nuclear wastes equally present an important chemical variability. Within PREDIS, Orano contributes to WP4 and WP7. Orano has also hosted WP3 training activities at their facilities.

Paul Scherrer Institute (PSI) is the largest research institute for natural and engineering sciences in Switzerland. PSI is responsible for the nuclear waste from medicine, industry and research in Switzerland, its conditioning operates the federal interim storage facility for these wastes. Based on PSI's large facilities (SLS and SINQ) and the know-how of its collaborators, the division is involved in three main topics of research: the safety of currently operating nuclear reactors, related fuel cycles, and long-term safety of deep geological repositories for nuclear wastes of all kinds. PSI coordinated and contributed to several EURAD WPs. In PREDIS, PSI is involved in WP7 focused on digital twin activities.

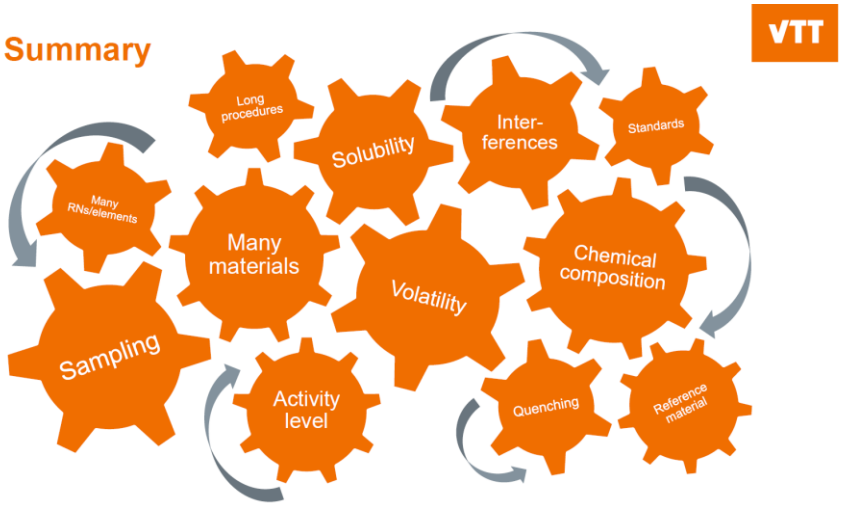
Newsletter #8 July 2024

Difficult To Measure (DTM) Radionuclides: progress and new challenges Webinar Summary

Summary

The webinar aimed to present advances in measuring hard-to-detect radionuclides for various applications, such as metal and concrete. It covered measurement innovations and future prospects. Radioactivity levels of these radionuclides can be determined through non-destructive methods, such as scaling factors or modelling, or through destructive methods involving selective extraction of the radionuclides. These approaches are complementary and offer a range of options for accurately assessing radioactivity levels. The welcome address and webinar objectives were given by T. Suzuki-Muresan from IMT Atlantique (France).

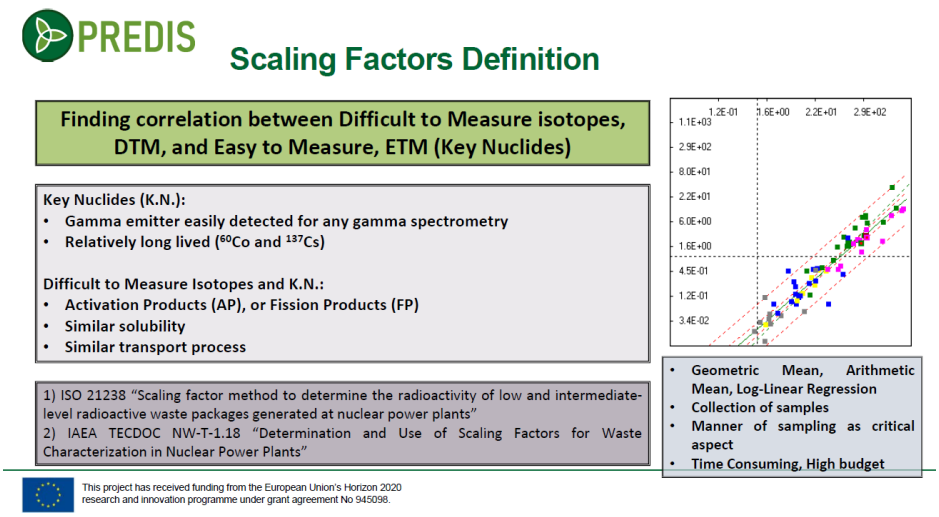
General introduction



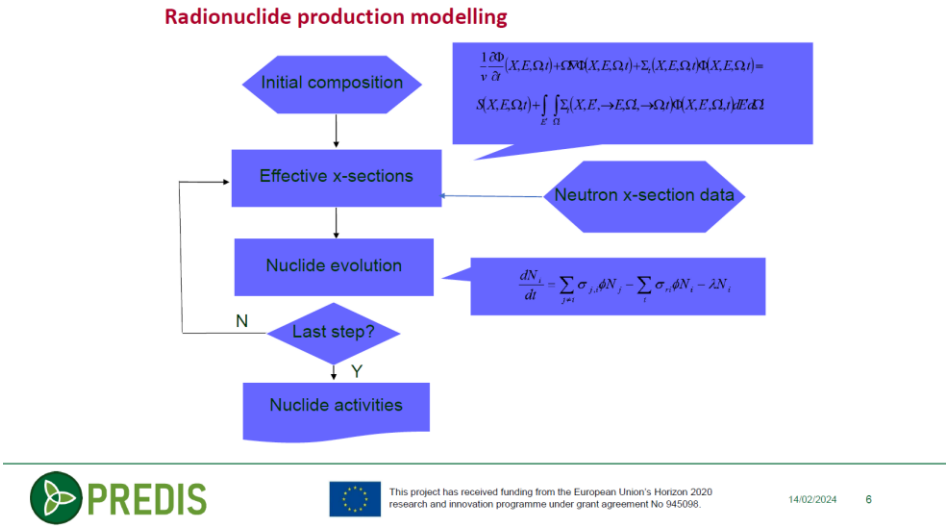
A. Leskinen from VTT (Finland) provided a comprehensive introduction highlighting the challenges associated with sampling, particularly in ensuring representativeness, overcoming technique-related issues, addressing contamination concerns, ensuring sampling accessibility, and managing time constraints, especially during dismantling operations. Several key points and challenges were explained, including the volatility of certain radionuclides during sampling, the physico-chemical constraints encountered during their extractions, the complexities involved in purification methods associated to time constraints and interferences, as well as the importance of utilizing sensitive detection methods and ensuring access to these instruments.

Non-destructive approach

The determination of the scaling factor, as presented by J. L. Leganes Nieto from ENRESA (Spain), represents a robust method for assessing the radioactivity of DTMs based on easy to measure radionuclides (ETM). This approach can employ both theoretical and empirical methods and relies on similarities in physicochemical properties and transport processes among materials. To minimize uncertainties associated with scaling factors in the uncertainty analysis, various methods are proposed: reducing the number of samples, incorporating two key radionuclides, considering composite materials. Following the refinement of the scaling factor model, its application to waste packages is feasible. Several questions are raised



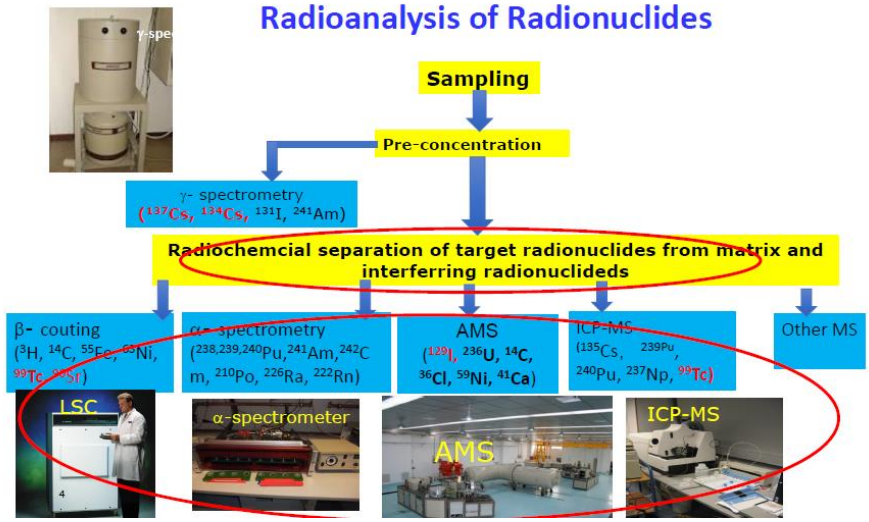
regarding the origins of biases and uncertainties associated with waste packages, as well as the representativeness of sampling.



As part of efforts to enhance the characterization of metal waste and implement cost-effective minimization and classification, A. Plukis from FTMC (Lithuania) presented the methodology for modelling activated materials and validation of models on real cases. The model is based on the process of production and distribution of radionuclides within a reactor considering its characteristics and its history. Using this approach, classification before dismantling by a modelling approach after validation of the model makes it possible to sort metal waste according to the level of activation. This approach has been applied to several reactors such as RBMK, BWR, VVER types. Finally, modelling is a supplementary tool for determining the activity of DTM nuclides, and the scaling factor approach helps minimize uncertainties.

Destructive approach

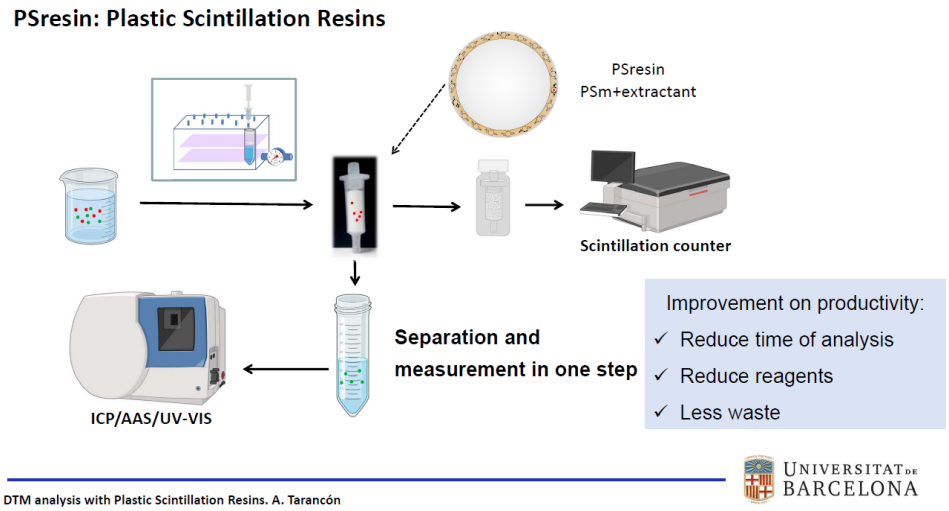
X. Hou from the University of Lanzhou (China) presented various analytical methods and approaches for measuring DTMs across different matrices. A key emphasis was placed on the need to develop rapid and precise procedures for assessing DTMs in a wide range of waste materials. This requires the development of radiochemical separation methods to target radionuclides, allowing for their isolation from complex matrices and interfering elements. Radiological characterization poses numerous challenges, notably the absence of reliable methods for accurately determining the most challenging radionuclides and the instability of volatile radionuclides during sampling, storage, and pretreatment. Consequently, there is a demand for sensitive and rapid measurement techniques, which can be achieved through the automation of separation procedures or the utilization of mass spectrometry methods. Many examples are provided to illustrate each challenge.



In pursuit of enhanced performance in radioactivity measurement, A. Tarancon from the University of Barcelona (Spain) introduced an innovative method utilizing resin-based scintillating plastics for selective extraction. This approach offers notable advantages, including improved productivity through reduced analysis time, reagent usage, and waste generation. Several examples were presented to illustrate the extraction selectivity for isotopes such as Tc-99, Cl-36, Sr-90, and alpha emitters. These scintillating plastics hold promise for future applications in waste classification, offering a simple, rapid, and selective solution, particularly for alpha and beta emitters.

Next challenges

The studies will continue as part of the Eurad2 project in the WP ICARUS (Innovative ChARacterisation techniques for large volUmeS). The objectives will target development, optimization and harmonization of innovative techniques for characterizing the radiological, physical, and chemical properties of LLW/ILW-mixed waste. These techniques are



critical for the safe implementation of radioactive waste management programmes, including destructive techniques (DT) on laboratory scale and its relation to non-destructive techniques (NDT) and scaling factors (SF) at the raw waste and package scale user cases.

Summary

The discussions included topics on general characterization approaches. For example, when are the analysis results good enough? Recommendations were made to establish clear criteria for the analyses e.g. limit of detection should be at least 10 times lower than the clearance limit. Discussions on the heterogeneity of reactor components included recommendations to carry out enough samplings to demonstrate similarity. Additionally, technical questions included the below topics.

Phosphoric acid

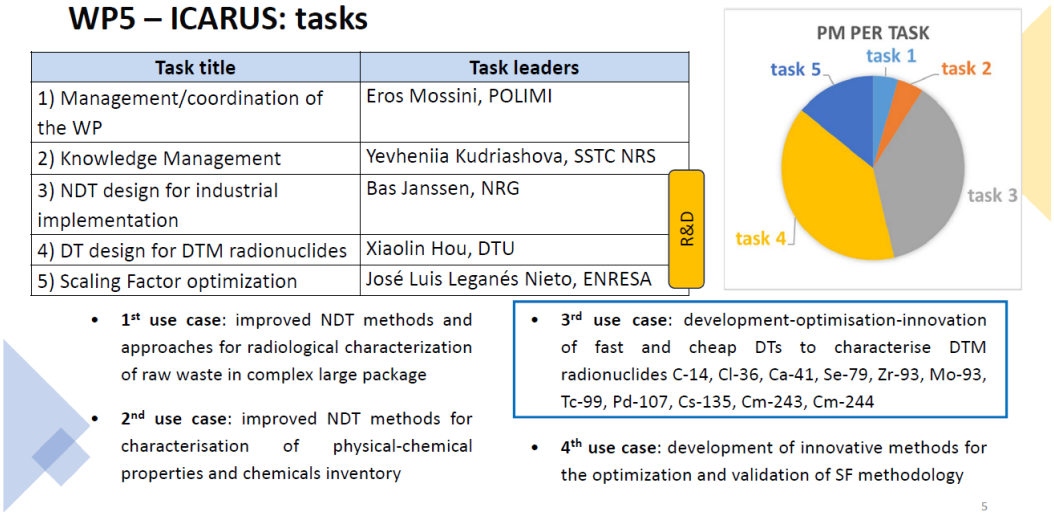
It is used to reduce quenching in samples. However, a low concentration of approximately 1M phosphoric acid should be used to avoid decomposition of the scintillation cocktail by the acid. It is considered compatible with scintillation cocktail such as Ultima Gold LLT, in a ratio of up to 6:14 ml

Presence of Fe in samples

High chemical quenching issues encountered when samples content Fe-55, particularly for samples with high iron concentrations, leading to potential false peaks. To solve this, the use of phosphoric acid (H3P04) is recommended, allowing up to 200 mg of iron to be dissolved in the sample to obtain a colorless solution measurable by LSC with an efficiency of counting more than 25%. The process involves evaporating the separated iron solution to dryness, followed by dissolving the residue in 1M phosphoric acid and subsequent mixing with a scintillation cocktail for LSC analysis.

Cl-36

The method of selecting the Cl-36 ($NaHCO_3$) trapping solution in the pyrolyzer shows that the use of dilute acids such as 0.1 M HNO_3 or 0.05 M H_2SO_4 is common to avoid the trapping of ^{14}C in the alkaline solution. The hypothesis of the speciation of Cl-36 in Cl^- form is put forward. Experiments have shown a total yield of 75% in real graphite samples.



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Newsletter #8 July 2024

Upcoming Events

There are no further upcoming events related to PREDIS. See also the PREDIS Events page for summaries of past events, including proceedings and webinar recordings.

Other events:

- 1-5.7.2024, IAEA International Conference on Nuclear Knowledge Management and Human Resource Development, Vienna, Austria.
- 23-25.10.2024 EURAD-2 project launch, Belgium.
- 25-28.11.2024, 9th International Clay Conference, Hannover, Germany.
- 12-16.5.2024, FISA-EURADWASTE 2025 conference (joint with SNETP Forum), Warsaw, Poland.

Recent publications

See also the PREDIS publications page.

- Deliverable 2.3 – Strategic Research Agenda
- Deliverable 2.6 – Guidance on waste form qualification
- Deliverable 2.7 – Guidance on formulating generic waste acceptance criteria
- Deliverable 2.8 – Governance Implementation Plan: PREDIS recommendations for the EURAD-2 Joint Partnership
- Deliverable 4.3 – Development of vacuumable gel decontamination process
- Deliverable 4.4 – Report on innovative decontamination process
- Deliverable 4.5 – Report on secondary waste management
- Deliverable 5.2 – Report on synthesis of formulation & process studies results
- Deliverable 7.2 – Two open-access articles on integrity testing and monitoring techniques
- Deliverable 7.3 – Report on innovative integrity testing and monitoring techniques
- Deliverable 7.5 – Report on digital twin and modelling technologies
- Deliverable 7.7 – Report on innovative data handling & decision framework technologies
- Deliverable 4.2 – Synthesis report on management of metallic waste streams
- Deliverable 5.3 – Report on Synthesis of conditioning matrix performances studies
- Deliverable 6.3 – Economic, environmental & disposability impacts of novel treatments
- Deliverable 7.9 – Economic, environmental, and safety impact
- 2024 *Cement and Concrete composites*, "Cementation of spent radioactive ion-exchange resin ashes using alkali-activated cements: Physicochemical and structural changes", Vol 149, March 2024, 105517, (authors from CSIC: P. Perez-Cortes, I. Garcia-Lodeiro, M.C. Alonso, F. Puertas), https://doi.org/10.1016/j.cemconcomp.2024.105517
- 2024 *Materials,* "MgO/KH2PO4 and Curing Moisture Content in MKPC Matrices to Optimize the Immobilization of Pure Al and Al-Mg Alloys", Vol 17, no 6: 1263, (authors from CSIC and UAM, C. Fernández-García, M.C. Alonso, J.M. Bastidas, I. García-Lodeiro and R. Fernández), https://doi.org/10.3390/ma17061263
- Domain Insights
  - DI 2.1.3 Technology Selection – Domain Insight
  - DI 2.2.1 Characterization – Domain Insight
  - DI 2.2.4 Storage – Domain Insight
  - DI 2.2.5 Transport – Domain Insight
- PREDIS Blogs on LinkedIn
  - Conditioning of Molten Salt Oxidation solid waste into geopolymer matrix
  - Separation and determination of actinides and Zircoium-93 from radioactive waste and mineral samples
  - Waste form qualification

Recent presentations

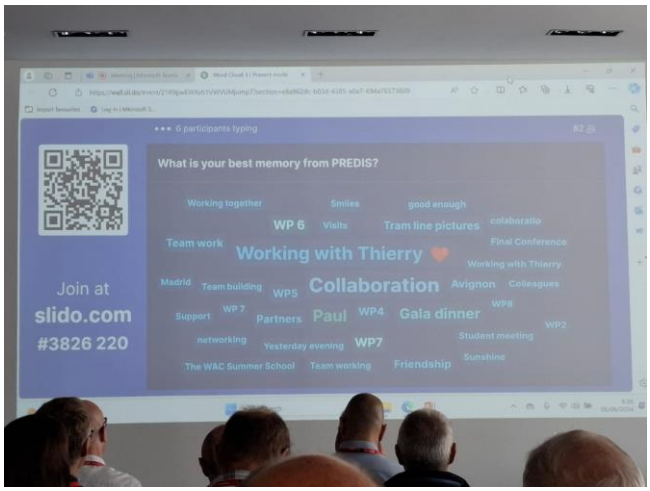
See also the Events page.

PREDIS/EURAD project events and their presentations:

- 22-26.1.2024, EURAD-MODATS online Training course on Monitoring in Geological Disposal facilities of radioactive waste.
- 23-25.4.2024, EURAD Annual Event (Final), Bucharest, Romania.
- 20-24.5.2024, Predisposal Domain Insight online training, 12 lectures (feeding into the EURAD Roadmap).
  - Presentations
  - Recordings
- 15-16.5.2024, LCA and LCC training at University of Manchester (UK).
  - General training slides
  - LCA-LCC workshop CCaLC brief
  - LCA-LCC workshop OpenLCA brief
- 3-7.6.2024, PREDIS final conference, Avignon, France.
  - Presentations

PREDIS-related work has also been presented in other events:

- 11-15.3.2024, Waste Management Symposium (WM2024), Phoenix, Arizona
  - Session co-chairs Erika Holt of VTT (Finland) and Anthony Banford of NNL (UK) were joined by Bruggeman Christophe of SCK CEN (Belgium), Rebecca Robbins of International Atomic Energy Agency (IAEA), David Sassani of Sandia National Laboratories (USA) and Jess McWilliams of The University of Sheffield (UK) in a panel on Collaboration between EU Waste Management Projects with Other International Groups held during the Tuesday afternoon session. The panel discussed many topics including PREDIS case studies on innovative solutions for pre-disposal waste management and engagement with international partners and the ways international stakeholders can benefit from collaboration with the EU R&D projects funded by Euratom. Other topics included stakeholder engagement within PREDIS and European Joint Programme on Radioactive Waste Management and readiness for EURAD-2 within which the collaborative plans were developed with various institutes in USA and Canada.



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Newsletter #8 July 2024

Highlights of the PREDIS Final Conference, Avignon, June 2024

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Newsletter #8 July 2024