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REVIEW ARTICLE

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Overview of knowledge management in EURAD

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Abstract. Knowledge management is a core activity for the European Member States (MSs) implementing the Council Directive EC 2011/70/EURATOM. Twenty-one MSs and two associated countries have mandated their respective radioactive waste management, safety and research organisations to contribute to the European Joint Programme on Radioactive Waste Management (EURAD). EURAD has established a Knowledge Management and Networking Programme which supports the capturing of knowledge and its transfer among organisations, Member States and generations. EURAD as a Joint Programming has an utmost advantage, compared to individual projects, as it provides:

- processes for knowledge sharing, for example interaction between the different radioactive waste management (RWM) actors to find out what is already known and what is most useful to investigate further.
- Resources and people to develop new knowledge and/or to support preservation of existing knowledge at risk, for example access to experts, networks and communities of practice.
- Tools and technology capable of handling different forms of knowledge, with a focus on socialising, signposting and aggregating existing knowledge sources.

This paper intends to describe the role of knowledge management and networking in EURAD, how knowledge generated by EURAD Workpackages and RWM organisations is captured and how we provide added value to MSs. Furthermore, it explains how we cooperate and work together towards common knowledge preservation goals with the EC PREDIS project, IAEA and OECD/NEA, to avoid duplication of work and maximise impact.

1 Introduction

Considerable scientific and technical knowledge has been acquired in Europe in the field of radioactive waste management (RWM) and deep geological disposal for over 40 years, fostering what is today a strong cooperation between implementers, laboratories and institutions. The first spent fuel and high-level waste disposal facilities are now close to realization in a number of European Member States (e.g., Finland [1], Sweden [2] and France [3]), while other disposal projects are at a rather early stage of implementation in a number of other EU countries [4].

In line with the European waste directive 2011/70/EURATOM [5], EURAD (the European Joint programme on radioactive waste management) launched in 2019, intends to make a step-change (from individual projects to an integrated programme) in European collaboration between advanced and early-stage programmes allowing for access to expertise, skills and technology on radioactive waste management and disposal

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[6]. Collectively EURAD pursues a more effective and efficient long-term-oriented use of public research and development (R&D) funding in Europe [7], building on the basis of activities and priorities of common interest of the three Colleges: European waste management organisations (WMO, represented by the Implementing Geological Disposal-Technology Platform (IGD-TP)), technical support organisations (TSO, represented by SITEX.Network), and research entities (RE, represented by EURADSCIENCE). EURAD aims to generate new and manage existing knowledge and to support Member States at various stages of disposal implementation. It is focussed on scientific and technological R&D, closely aligned to implementation needs, safety considerations and an ambitious knowledge management programme.

Working together, the EURAD Colleges have jointly developed a strategic research agenda [8] which in 2022–2023 will undergo a periodic update to take account of recent developments and integrate knowledge management (KM) issues identified by EURAD and the European project on Predisposal Management of Radioactive Waste (PREDIS) [9,10]. This foundational work in KM, completed in the first half of EURAD, has established a basis to understand what exists already, what complementary pipeline activities are planned by international radioactive waste management (RWM) organisations (IAEA, OECD/NEA and EURAD Colleges) and to gather the specific needs of the EURAD community. The Joint Programme has established the EURAD Roadmap [11,12] as a central tool for organising and coordinating its Knowledge Management and Networking Programme 2020–2024 [13]. Four dedicated KM Work Packages have been established to learn and test what works well, to hear feedback from contributors and users, to adapt approaches, and ensure that we maximise impact. The programme will remain reactive and responsive to the knowledge management and networking needs of the EURAD community, the pre-disposal community within the PREDIS project (associated to EURAD), and other interested organisations, including IAEA and OECD/NEA.

This paper focuses on how the EURAD KM is structured, operated and extended to PREDIS, on the goals, views and accomplishments (lessons learned) and provides an outlook on the perspectives beyond HORIZON 2020 (EU's research and innovation funding programme from 2014–2020).

2 Role of KM in EURAD

The European Joint Programming in Radioactive Waste Management is founded on the step-change as described in the EURAD vision [14], i.e., moving from individual projects to an integrated programme promoting collaboration and networking between different actors (WMO, TSO and RE). The Joint Programme provides an opportunity for national programmes to collect, share knowledge and experiences, organise (in a common way) a preservation and transfer knowledge between organisations/programmes and for future generations [15].

This requires acknowledgement of existing RWM knowledge structures and networks, developed over 30 years, and how this is codified and accessible in the various documents, procedures and processes, organisations, and people of the broad RWM community.

The role of KM in EURAD is therefore to better harvest this existing knowledge and integrate with it newly created knowledge, giving weight to:

- improved orientation of knowledge – how knowledge contributes to specific implementation goals and activities in radioactive waste management;
- improved definition of needed competences – what level of proficiency is needed and available to support programmes;
- improving accessibility to knowledge by signposting to people and documents – promote networking;
- use of a common structure, digitisation, or other codification activities – how knowledge is documented, stored and easily reused;
- improving socialisation, training, and networking – how knowledge is transferred and spread.

Where there are risks of knowledge loss or opportunities for improved knowledge preservation and transfer, the Joint Programme can support addressing such issues (partly using a small internal budget, or through future SRA, channelling information to EC or by other means) and by leveraging the access to the broad RWM network. It cannot be enough stressed that the Joint Programming for the first time collects a large part of European expertise, covering WMO, TSO and RE aspects, in one collective RD&D, Strategic Studies and KM and Networking programme, thus creating a platform for collaboration, networking and communication. Currently EURAD has four dedicated workpackages (WPs) to deliver the specific KM actions:

- WP1 EURAD Roadmap – activities to orientate people to existing knowledge via a generic roadmap for implementing radioactive waste management, leading to disposal. This provides an integrated and systemic framework for organising, structuring and sharing available RWM knowledge.
- WP11 State of Knowledge – documents with experts' view of the most relevant knowledge and associated uncertainties in a specific domain applied in the context of a radioactive waste management programme.
- WP12 Guidance – activities consisting of developing a comprehensive suite of instructional guidance documents that can be used by Member States with RWM programmes.
- WP13 Training and Mobility – activities consisting of developing a diverse portfolio of tailored basic and specialised training courses taking stock of and building upon already existing initiatives and creating new initiatives to bridge the identified gaps.

3 EURAD KM positioning in the European RWM landscape

Reformulating a definition given by IAEA [16] EURAD knowledge management is:

> *An integrated, systematic approach to identifying, managing and sharing an organisation's knowledge and enabling groups of people to create new knowledge collectively to help in achieving the objectives of radioactive waste management including geological disposal of radioactive waste.*

A survey [17] among European RWM organisations within EURAD (WMO, TSO, RE and Waste Generators) has shown that knowledge management is gaining a wider interest and support in view of the generation change and necessity to transfer tacit knowledge between generations. The survey reviewed existing and available knowledge management approaches and tools in use (or being developed) and has established a basis for what KM challenges exist. The survey is further complemented by ongoing exchange and cooperation activities with IAEA, OECD/NEA and PREDIS to identify those KM and networking activities that are of most value to conduct within the EURAD. A key output of this work has been the recognition that IAEA KM activities are positioned at a policy level, whereas EURAD is able to pursue KM activities hands on and at a more practical level.

The EURAD KM survey identified that most organisations in EURAD are in varying degrees of advancement towards the establishment of internal KM systems (i.e., a system is in place or planning has started to prepare for implementing a KM system). It can be remarked that only few large European organisation provide "pure" knowledge management on RWM; generally, KM is integrated in the knowledge production activities such as Research and Development (R&D), of which KM is a small part. Among "pure" KM activities supported by EC, one could mention the on-going ENS [18], ENEN [19] programmes and, from the past 10-year period, ENEN+ [20], ANNETTE [21], PETRUS III [22] and A-CINCH [23].

In addition to nuclear KM activities supported by the EC, there are a number of national initiatives and RWM schools [24–26]. These are complemented by the large cooperation efforts coordinated by international nuclear organisations, such as SNE-TP [27], the IAEA [28–33] and OECD/NEA [34–36]. Even though there are a large number of KM initiatives, few programmes, schools and training organisations provide the full "cradle to grave" and systematic, comprehensive and contextualised structure that covers all activities and needed competence for all phases of a radioactive waste management programme.

It is this KM niche that EURAD can support by aggregating the components that exist already, i.e., signposting to existing knowledge bases and available guidance, identify important lessons learned, connecting people and organisations to experts and communities of practice (CoP) and providing a platform to share knowledge and network across Europe.

To organise and structure this effort, the EURAD roadmap has been established [11,12], which is now being populated with latest state-of-knowledge documents written by experts in the area and complemented with latest references to needed capabilities (competences and infrastructures), training courses and guidance documents. Many of these components are provided individually by some of the knowledge providers; however, it is the completeness of the EURAD roadmap structure and hierarchy of information organised at different levels of detail, which provide an entry point for different actors (RWM managers, waste producers, regulators, scientists, students and public).

This allows all actors to access and contribute to the EURAD roadmap and find relevant information for them [37,38]. For the moment, EURAD uses a Wiki platform to structure the roadmap and its population with State-of-Knowledge documents making the content easily accessible to experts and students, and provides easy navigation across 80+ RWM domains. The roadmap currently involves signposting to relevant content (as rated by experts) so that we capture first the knowledge which has already been gained worldwide in RWM. Second, through assessment of the population of the roadmap, we can identify gaps and identify new needs. It is not only explicit knowledge that is provided on the Wiki platform and connected to the EURAD School of RWM, but also the possibility for all actors to interact via a chat function and form networks, including Communities of Practice, in many disciplines.

An important contribution to acquiring and making use of the knowledge is provided by the EURAD Guidance work package that feeds the State-of-Knowledge (SoK) documents with existing, but also newly produced guidance (on topics where guidance is missing and asked for by MSs). These guidance documents support the MSs with tacit knowledge on how to implement a RW disposal, also providing examples [37,39].

Complementing the explicit knowledge, the EURAD School of Radioactive Waste Management (School of RWM) is creating a hub where information on past and present training courses exists, latest information on RWM conferences and a chat function for students to meet senior researchers, thus supporting networking [40,41].

It is also worth to mention some limitation/opportunities/challenges of EURAD in comparison to KM performed in large non-nuclear companies, such as:

Opportunities

- As a Joint Programme, there is opportunity to change, adapt and re-shape tasks.
- Maximise the KM, R&D and strategy output while profiting from access to EU's expertise in RWM field.
- Covering general broad aspects (roadmap, strategy) as well as specific ones (R&D, guidance).
- Very diversified and specialised work groups (scientists, technologists, engineers, experimentalists, modellers, programmers, and many more), having different roles as implementers, technical support organisations (supporting regulators) and researchers.
- Access to a wide pool of external experts and mechanisms for technical governance and strategic oversight

(EURAD External Advisory Board and Chief Scientific Officer).
- Involving end-users, stakeholders and civil society to steer the programme and review our advancement.

Challenges

- As an organisation or entity, EURAD is newly created, and continuously evolving.
- Adaptation of resources and working parties, since the programme changes every 5 years.
- Requires a broad scope to support the advancement and implementation of national disposal programmes.
- A significant fraction of contributors consists of short-term participants (MSc, Ph.D., PostDoc and young scientists).
- EURAD knows what to develop, but needs to avoid competition and respect complementarity with national RWM companies and international organisations (e.g., IAEA, OECD/NEA).
- Establishment of a business case for a broad commitment to a joint activity on KM (SoK, guidance and training) based on and taking into account continuous end-user feedback.

4 KM in EURAD

EURAD KM activities are an integrated part of the EURAD vision [14], shared also by the PREDIS project:

> *A step change in European collaboration towards safe radioactive waste management (RWM), including disposal, through the development of a robust and sustained science, technology and knowledge management programme that supports timely implementation of RWM activities and serves to foster mutual understanding and trust between participants.*

To underline the importance of knowledge management in EURAD, this vision is complemented with a specific vision on knowledge management [14]:

> *It is essential to implement an efficient and integrated Knowledge Management programme at the EU level in order to establish, capitalize and transfer the state of scientific and technical knowledge in the field of RWM.*

EURAD's KM vision emphasises the principle that KM is part of every EURAD component: the Project Management Office (PMO, WP1), ten R&D WPs, two Strategic studies WPs and three KM WPs, Figure 1. Each work package contributes to knowledge production, knowledge management, networking or dissemination of results.

Within this overall structure, the three colleges (WMO, TSO and RE) contribute through position papers sharing their view on KM with the Bureau and PMO that are brought forward together with opinions of the External Advisory Board and Chief Scientific Officer to guide the update of the EURAD roadmap and connect knowledge production, management, networking and/or dissemination of results.

The EURAD roadmap gives a structure for all collected knowledge and functions as mainly explicit knowledge hub, incorporating knowledge from all EURADs WPs and by external experts. The ten R&D WPs and the two strategic studies WP support the knowledge management as knowledge providers. This is done through writing of State-of-the-Art (SotA) documents, which on a fine granular scale address end-user need-defined research topic. The ten R&D and the two strategic studies WPs are;

- WP2 – Assessment of Chemical Evolution of ILW and HLW Disposal Cells (ACED), involving a multiscale approach and process integration to improve long-term modelling and assessments;
- WP3 – Cement-Organic-Radionuclide interactions (CORI), oriented to improved understanding of the role off organics (either naturally occurring or as introduced in the wastes and their influence on radionuclide migration in cement based environments);
- WP4 – Development and improvement of numerical methods and tools for modelling coupled processes (DONUT), focussed on improved understanding of the upscaling THMC modelling for coupled hydro-mechanical-chemical processes in time and space;
- WP5 – Fundamental understanding of radionuclide retention (FUTURE), addressing quantification of long-term entrapment of key radionuclides in solid phases to inform reactive transport models and the influence of redox;
- WP6 – Mechanistic understanding of gas transport in clay materials (GAS), concentrating on to increase understanding and predictability of gas migration in different host rocks;
- WP7 – Influence of temperature on clay-based material behaviour (HITEC), tackling improved THM description of clay based materials at elevated temperatures;
- WP8 – Spent Fuel characterisation and evolution until disposal (SFC) aiming at reduce uncertainties in spent fuel properties in predisposal phase;
- WP9 – Waste Management routes in Europe from cradle to grave (ROUTES) is dedicated to share experience and knowledge on RWM routes between WMOs, TSOs and REs from different countries, with programmes at different stages of development, with different amounts and types of radioactive waste to manage;
- WP10 – Understanding of uncertainty, risk and safety (UMAN), intends to further refine methods to make sensitivity and uncertainty analyses and the development of multi-actor network for uncertainty management;
- WP15 – Container corrosion under disposal conditions (CONCORD) addresses to optimise and evaluate the behaviour of materials for disposal containers in view of their long-term barrier performance;
- WP16 – Chemo-Mechanical aging of cementitious materials (MAGIC) focussed on increasing the confidence in Chemo-Mechanical simulations by reducing uncertainties in input data and understanding of key coupled processes, and

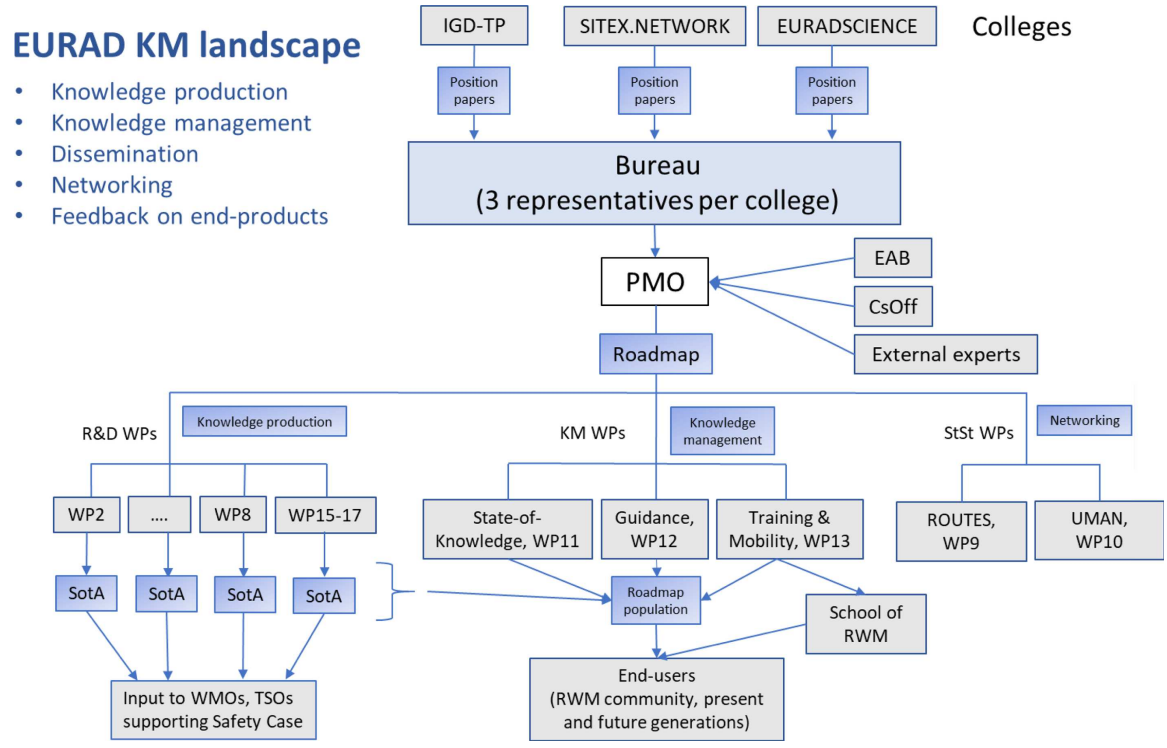

Fig. 1. EURAD knowledge management structure.

- WP17 – Monitoring equipment and data treatment for safe repository operation and staged closure (MODATS), aims to evaluate, develop and describe methods and technologies, and to provide the means to measure, treat, analyse and manage data in a consistent manner.

The R&D WPs are contributing also through creation of courses to disseminate their achievements. It needs to be pointed out that that the current R&D WPs and strategic studies WPs cover only a small part of the overall KM of relevance for implementing disposal solutions.

The three KM WPs (State-of-Knowledge, Guidance and Training & Mobility) manage the core of knowledge management in EURAD. Their tasks are all need-driven and the work prioritised by the three colleges (through General Assembly decisions). The State-of-Knowledge WP, with the help of external experts, is populating the roadmap with State-of-Knowledge documents in all relevant RWM thematic. The SoK documents are arranged in a hierarchical order with increased amount of details including (from the top-level) Theme Overview, Domain Insights, State-of-Knowledge and State-of-the-Art (SotA) documents [37]. The top-level documents are 10–15 pages long and sign-post to existing knowledge blocks. They are produced through engagement of external experts and include also input from the Guidance and Training & Mobility WPs.

The Guidance WP identifies "missing" guidance through a top-down (input from experts with overview of the disposal implementation process) and bottom-up (scanning the EC CORDIS, EU RWM organisations and international organisations) approach. The WP team writes the guidance document when competences exist within the WP or uses EURAD internal/external experts. The training and mobility WP is likewise focussed on identifying/defining previous, existing and planned, "missing" or requested courses by the EURAD partners or MS RWM organisations. The newly produced courses are mainly provided by organisations such as IGD-TP, the SITEX.Network and EURADSCIENCE, or by EURAD partners. A common EURAD School of Radioactive Waste Management [40] has been created by the Training & Mobility WP, gathering and collating all information relevant to young scientists and EURAD students (as of July 2022: >100 MSc, Ph.D. and Postdocs) as well as giving access to networking (within EURAD, but also with external RWM organisations). The School of RWM functions as a hub where students and partners can receive information on RWM issues through, for example, EURAD Lunch & Learn lectures, webinars, workshops, conferences, access large EU infra-structures (e.g., underground laboratories, hot-cells and large computer centres), learn about job-positions, and requests for EURAD mobility actions. The School of RWM performance is continuously improving its performance based on feedback from students and supervisors that participated in, for example, student meetings and trainings and performed mobility actions.

5 Interactions, integration and exchange

This section aims to describe the KM interactions in EURAD among partners and WPs, integration with other

EC-funded projects (e.g., PREDIS) and exchange with external organisations (IAEA, OECD/NEA).

5.1 Interactions within EURAD

The KM WPs jointly defined and wrote the EURAD Knowledge Management and Networking programme (KM+NW programme) [13] that was sent for consultation to PMO, the colleges (IGD- TP, SITEX.Network and EURADSCIENCE) as well as PREDIS coordinator. The programme was adopted at the EURAD General Assembly N° 4. The main attributes of the integrated KM and Networking programme are that:

- it is centred around the Roadmap with its individual cornerstones: contextual insight (theme descriptions, Domain insight, SoK), competences, guidance, training and access to infrastructures (mobility) oriented to the needs of future users;
- it describes the dependence and interactions between EURAD RD&D, Strategic Studies and KM WPs;
- it foresees more intensive interactions/feedback with RWM end-users to guide the knowledge production;
- it outlines the importance of EURAD collaboration and networking with national RWM communities, ongoing projects (in particular PREDIS) as well as with international organisations, such as IAEA and OECD/NEA;
- it addresses future challenges and risks, as well as defines the success criteria, and
- helps to structure the future KM work in terms of what can be realistically achieved by 2024.

The transfer of knowledge between generations is a central theme in EURAD and is carried out by supporting the different national organisations in this task. The School of RWM forms a hub around training and mobility. The activities are focused on cohesions between EURAD-PREDIS students (to promote networking), as well as interactions between students and experts in EURAD R&D WPs and with RWM end-users through the School of RWM chat function and a physical or virtual coffee corner at EURAD's annual events to promote students' future career. Furthermore, the School of RWM provides Lunch & Learn sessions that are 1 h lectures on actual and requested topics in the RWM field and are open to the public. The total number of students in EURAD and PREDIS is close to 140; this is a significant number of potential future RWM actors carrying forward EURAD's accomplishments.

5.2 Integration with other EC-projects

The strong link between EURAD and PREDIS is based on the joint interest of radioactive waste management from "cradle to grave". So far, after almost three years of EURAD and one and a half years of PREDIS, the two programmes are running largely integrated with each other, with a strong interaction in the KM area.

In order to further strengthen project interactions, a number of KM-related initiatives have been started, such as:

- publishing a joint PREDIS-EURAD statement on knowledge management, defining the complementarity and interactions between the programmes;
- common webinars (3–4 h workshops, with a mixture of oral presentations and break-out rooms discussion to reach consensus on specific questions or topics);
- exchange of student participation to student sessions in the two programmes;
- defining Theme 2 (Pre-disposal activities) in the EURAD roadmap and populating it with State-of-knowledge documents, such as the Theme Overviews and Domain Insight, which is part of PREDIS KM WP's responsibility;
- joint initiatives, such as common posters, scientific publications, papers and presentations.

Integration with presently running or recently ended EC-projects such as MICADO, SHARE, CHANCE and DISCO provides additional input through the corresponding projects' KM activities, such as R&D outcomes (input to SoK document) and trainings and mobility that are registered among the training offers and announced on the School of RWM website. These projects are integrated with the EURAD knowledge management work and used to identify shortcomings or knowledge gaps stemming from these projects that could lead to future post-EURAD activities.

5.3 Exchange with external organisations

EURAD strongly interacts with international knowledge providers such as IAEA and OECD/NEA, to avoid KM overlaps and duplication. A rough differentiation of the KM activities among the three organisations is that IAEA works more on the policy level, OECD/NEA is identifying and work on different KM aspects/methodologies (Information, Data and Knowledge Management, IDKM) related to RWM while EURAD is closer to the "hands-on" work, supporting integration of KM for the R&D disposal implementation.

EURAD, having reached its mid-term is now profiting from the vast and complementary KM activities ongoing at IAEA [42] and can benefit by signposting relevant IAEA documents; in other areas, EURAD KM can benefit from the large supply of KM trainings and RWM guidance documents.

A certain degree of interactions with OECD/NEA (IDKM) was there from the beginning of EURAD and EURAD's Chief Scientific Officer has a delegate mandate to join OECD/NEA regular bodies as an observer. Furthermore, there is an ongoing collaboration with OECD/NEA on safety case training, where OECD/NEA will provide training input.

Interactions with external organisations is intensive, especially between the R&D and Strategic studies WPs with their end-users giving input to both R&D, strategy and indirectly to KM. Furthermore, a large number of experts from external organisations and companies, such as roadmap advisory board, guidance WP editorial board, External Advisory Board and EURADs programme end-users, are engaged to give advice on EURAD's KM programme.

6 Lessons learned

It is time to appraise our KM efforts and draw conclusions on what we still can improve during the second half of EURAD, until 2024, and also give some hints on what could be proposed for a possible follow-up of EURAD. EURAD KM has so far progressed very well and is on a good way; a conclusion shared with the EC mid-term assessment committee. The collaboration among the three KM WPs is very well developed and looks promising for the future.

Five basic challenges defining EURAD's goals remain in focus for the future:

- how can KM help to improve the cross-WP collaborations in EURAD to prove that EURAD is making the step-change, from past individual projects to an integrated programme?
- How to integrate and contextualise critical information from knowledge providers on key issues?
- How do we improve and speed-up transfer of knowledge between advanced programmes and early-stage programmes, also considering knowledge generated in previous EC programmes?
- How do we promote transfer of knowledge between generations?
- On a long-term perspective, how do we keep alive EURAD building blocks, roadmap, Strategic Research Agenda, continuation of R&D initiatives and KM structures in near-future and for future generations?

In the following sections of this paper, we discuss the aspects outlined above on two time scales: until the end of EURAD (2024) and after the end of EURAD.

6.1 Until 2024 (end of EURAD)

The initial period of the EURAD programme was mainly focused on getting the programme to function and to fulfil the requirements from EC; from the governance point of view, this included the update of the EURAD roadmap, the production of initial SotA in the R&D WPs and the setup of procedures and methodologies in the KM WPs. The second year was concentrated on the selection of the second wave R&D WPs and the re-direction of the KM programme. Approaching the end of third year, we are reflecting on what we would like to accomplish until the end of EURAD.

How can KM help to improve the cross-WP collaborations in EURAD?

The KM WPs of EURAD have identified a lack of experts within their WPs to cover the themes of relevance for KM. This was also observed in the PREDIS project. The two programmes identified that the mobilisation of EURAD and PREDIS communities towards KM activities may not be sufficient and therefore involvement of external experts is needed. Thus, a significant effort is necessary before being able to fulfil end-user needs and expectations. Attempts are ongoing to improve the situation by involving external experts.

A deficit identified within the KM WPs, but that is valid for the whole consortium, is that, despite efforts for strong and lasting interaction, there is still a too weak inter-WP interactions. These interactions are the cornerstone of a joint programme, and the full potential of the programme is not utilised until all partners have knowledge of and insight into all WP activities and exercise cross-WP collaboration with mutual integration. This is a part of the step-change that EURAD is targeting.

In this process, the KM WPs can bridge the R&D WPs via their input to the roadmap structure and SoK production (e.g., identifying capabilities, guidance, teaching in training courses, offering mobility places, reviewing SoK documents, holding webinars, writing State-of-the-Art papers and giving Lunch & Learn sessions), to make more visible the inter-dependence between different R&D roadmap topics. Nevertheless, there are still missing competences within EURAD to cover all the RWM issues and external support is therefore a key issue.

To reinforce the interaction between the KM WPs and the other EURAD WPs, KM representatives are present at the meetings to bring the science into the KM and the KM activities into the R&D and Strategic studies WPs, so that KM becomes a natural part of these WPs. The benefit identified goes in both directions: all R&D WP members are aware of the possibilities for trainings and mobility and get support for their internal WP KM work, while the KM WPs can tap in on the huge expertise that exists within the R&D WPs for authoring State-of-Knowledge documents, reviews, producing training materials and giving trainings, as well as arranging for students' mobilities both inter- and intra-WPs and possibly to external RWM organisations.

How do we improve and speed-up transfer of knowledge from advanced programmes to early-stage programmes?

One of the central tasks within EURAD, involving KM, R&D and Strategic Studies (with inclusion of external experts), is to stimulate collaboration and networking between early-stage programmes and advanced programmes, to transfer knowledge to the early-stage programmes for their implementation of their radioactive waste management and disposal solutions. This is a challenge as the advanced programmes often have their associated business companies that are selling services related to their experience. Furthermore, there are less and less experts available with a broad overview "from cradle to grave", due to a generation change. EURAD needs to use these scarce expert resources where they are urgently needed. EURAD KM will therefore target crucial areas where only partial support from advanced programmes is needed. The support given is through identifying the needs and giving the main direction on how to proceed, while the early-stage programmes are "learning by doing". At the end of his process, the advanced programme will review the outcome. It is in this iterative process that tacit knowledge is transferred. The outcome of this process might take time and be noticeable in future EC national reports [43] on the implementation of the radioactive waste and spent fuel management directive and IAEA's ARTEMIS review programme [44] describing progress of MSs' RWM programmes.

Additionally, EURAD KM intends to stimulate the creation of Communities of Practice (CoP) where practitioners regularly meet over specific subjects and

share their knowledge and advancements. A first step in this direction is that EURAD KM WP leaders will initiate a pilot KM CoP consisting of EURAD KM participants, but with the intention to extend it and invite experts that have been involved in EURAD KM activities and/or interested to use their knowledge management competences. The intention is not only to gather first insights into how CoP might work, but also to learn from existing CoP, such as the IAEA networks on International Network on Spent Fuel Management – SFM Net [30], Underground Research Facilities Network for Geological Disposal – URF Network [33], International Predisposal Network – IPN [29], where some EURAD partners are already participating.

How do we promote transfer of knowledge between generations?

With world's first deep underground repository for spent nuclear fuel being licenced for both construction and operation in Finland and Sweden (in January 2022) a milestone has been reached [1,2]. It marks a 40-year long era of not only research and development but also public involvement to support a safe disposal in Scandinavian granitic bedrock. The huge amount of knowledge, created and managed by a presently partly retiring workforce needs now to be transferred to the next generation of RW managers. While this is a principal mission of the national WMO and TSO, EURAD may help to support this knowledge transfer between generations. In that respect, it is important for the new managers to not only obtain new knowledge, but also acquire the "old" knowledge, such as why were things done as they were, what were the pitfalls that were never published, under which assumptions were decisions taken and many such historical questions will turn up in the future and need to have an answer for the upcoming regular licences. Even though EURAD will not be able to capture all this tacit knowledge, it needs to find methods and processes to capture tacit knowledge and turn it into explicit knowledge to be passed on to the RWM organisations. In this respect, also research entities (active in the RWM domains) play an important role as much of the research and development was performed in close cooperation between RE and WMO.

With that insight, one perceives that today's RWM students will play an important and difficult role in the future, needing to know about the past, present as well as the future of the waste management routes. In that respect, it is important to build networks, sharing all that knowledge and maintaining it active to consult an expert when needed. EURAD KM provides all types of networking opportunities. Networking requires visibility and contact surfaces, which EURAD KM is promoting through students' presentations at EURAD's scientific workshops and events.

Activities are undertaken (student days, student personal and scientific presentations) to create cohesion between students in the Ph.D. group and to get students to speak with one voice, so that the EURAD knowledge management activities can more effectively respond to students' needs.

On a long-term perspective (15–20 years), how can we contribute to ensure that knowledge created in EURAD, PREDIS and other initiatives remains useful to future generations?

We are convinced that the need-driven path via the structuring of the existing knowledge in the form of SoK, SotA and its links (signposts...) and contexts to other knowledge providers and communities of practice in the roadmap is a path that has the potential to survive generation changes. There is an increasing awareness to assure that the EC, REs, TSO and RWM organisations' investments in EURAD, PREDIS and other projects/programmes, in the form of manpower, knowledge accumulation (all reports and scientific publications), R&D output (SotA), knowledge structuring and contextualising (populated roadmap), will be used regularly, retained and conveyed into close future (15–20 years) and for future generations. The condition is that the KM platform of EURAD is regularly used by the national programmes and feedback is integrated. Links to other initiatives should be transparent, making clear that no duplication of work is foreseen, while maintaining the need of access to critical knowledge by the national waste management programmes of all Member States.

Before the end of EURAD, we need to have a solution for the hosting of the platform (possibly Wiki) containing the roadmap, theme descriptions, the Domain insights and the SoK documents. Furthermore, a solution needs to be found for hosting the School of RWM. These tasks need to be with an organisation that ensures the longevity of the system, making the platforms accessible to all Europeans (possibly to the world in a similar manner as IAEA), investing competent resources to keep the software programme up-to-date, maintaining the IT-hardware, control the content accessibility and working with future generations to update the content. However, only if the next generation uses the EURAD KM platform, it will survive.

6.2 A follow-up of KM beyond EURAD

In view of the long implementation times for RW disposals and considering that MSs are at different phases of their disposal programme, there is increasing awareness on the need for a long-term vision for knowledge management in Europe.

Based on the lessons learned, we can already identify some elements of what could be useful to consider while establishing a long-term KM programme. Building on the strong support of the EC to promote the KM in EURAD for a long-term vision, a strong support by the national programmes and the colleges is also essential. In that process, the national KM programmes (WMO, TSO and RE) need to be engaged in shaping and designing the future orientation of a long-term European KM programme driven by the largely varying and evolving national needs from programme initiation to implementation.

A future KM programme might become even more than today a central part in continued European Joint Programming, providing a visible platform for interaction to ensure active and effective knowledge transfer, including training and mobility, networking, and creating or contributing to Communities of Practice.

The School of RWM could function as a market place, or an active platform, where end-users with identified needs, using the EURAD roadmap, meet the knowledge providers/producers to optimise the European

R&D efforts and exchange knowledge between MS organisations and across generations.

7 Summary

EURAD has materialised from ideas to a real and functioning Joint Programme, through a step-wise integration of the three components; R&D, Strategic studies and Knowledge Management and the commitment of the three colleges.

The first half of the 5-year long joint programme has taught us how important it is to communicate and engage all actors: researchers, technical support organisations, disposal implementers, end-users, stakeholders (such as EC, external experts, waste generators, regulators and international bodies e.g., IAEA and OECD/NEA) and the civil society, to become a successful programme.

Throughout this time, the knowledge management activities have been focused on the design of the EURAD roadmap and to populate it with components, such as needed capabilities, state-of-knowledge documents, guidance and training. In this way, the EURAD roadmap has become the central structure in the programme that unites the partners in striving to complement and integrate understanding of the coupled processes that are necessary for implementation of a radioactive waste disposal. Entering the second half of the programme necessitates the reflections of what we have achieved so far, what remains to be done and how the "lessons learned" can be used to improve the present programme and possibly shape a follow-up programme beyond EURAD. One of the stronger recommendations is that KM should be an integral component in all R&D and strategic studies work packages. It is the actual usage of the EURAD KM platform, by the existing and coming generations, that decides if it will survive. With that statement comes a requirement on how to assess, in an objective and measurable way, the usefulness of the EURAD KM platform.

It cannot be stressed enough that a successful future programme and useful knowledge management for the coming generations depend on a strong end-user engagement and a long-term commitment.

Conflict of interests

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All authors equally contributed to this work.

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